Developing a Phaistos disk geometric model with 3d scanning technologies

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Abstract
One of the most widely known artefacts from the Minoan times is the Phaistos disk. The disk's two sides bear 242 signs, of a syllabic script combining the Linear B and Linear A scripts. The language of the Disk is unknown, and so the text cannot be understood. Nevertheless, this has not deterred many potential deciphering attempts. There have been more written about this Cretan inscription than any other, but it is pure guesswork.
In this work a three dimensional geometric model of the Phaistos disk was developed employing three dimensional scanning technologies. An accurate replica of the disk with respect to the shape, size and texture was created using a Konica Minolta non-contact laser scanner. The three dimensional geometry and texture of the model were captured as a cloud of points. Twenty one scans were taken, producing a cloud of about 4.5 million points out of which a 2.5 million triangles mesh was created.
Several critical parameters are required for these scans, such as the environment, the lighting, which needs to be ambient, the shadows, the distance between the scanner and the disk, the inclination of the scanner and the angle of each scan. In order to develop the geometric model, each scan required editing, where overlaps had to be removed and all individual scans joined together to produce the complete three dimensional geometric model of the disk. The texture on the disk was also edited to reduce colour gradation due to lighting variations and shadows. This work was performed during an internship placement in the Laboratory of Precision Machining and Reverse Engineering (PMRE Lab) of the Mechanical Engineering Department, of the Technological Education Institute of Crete.

Keywords: Phaistos disk, 3d scanning, Reverse engineering

Introduction

3D reconstruction has been gaining interest for cultural heritage digitization, due to its contribution in digital recording, documentation and preservation of the artefacts, as it has visualization and reconstruction capabilities. This is essential to heritage (natural, cultural or mixed), as they suffer from on-going attrition and wars, natural disasters, climate changes and human negligence (Remondino 2011).

Many successful applications have been reported using various technologies to reconstruct archaeological discoveries (Arbace et al.

2013)(Fontana et al. 2002)(Bruno et al. 2010)(Gomes et al. 2014) such as the Antikythera mechanism (Ramsey 2007)(Yan n.d.). With these methods archaeological places were visualized (Haddad 2011) or many valuable paintings were studied such as the Mona Lisa (Cornelis et al. 2011) (Ribes et al. 2008). Also, these methods can be used to study and compare the human anatomy and its changes over time, i.e. studying the differences in skulls between ancient and modern Greeks (Papagrigorakis et al. 2011). However, high-resolution 3D reconstruction of the Phaistos disc still remains a challenging issue for researchers.

The Phaistos Disk is the best-known Minoan inscription. It is accepted that this can be read spirally, i.e., from the rim inwards. |Being 16 cm in diameter, the disk's two sides bear a total of 242 signs which can be divided into 61 groups. There are 45 different signs on the Disk, too many for them to constitute an alphabet and too few for them to constitute a truly ideographic script, as it is the case with Chinese. This observation enables scientists to deduce that it is also a syllabic script, as Linear B and Linear A.

It goes without saying that the language of the Disk is unknown, and thus the text remains beyond peoples reach. Nevertheless, this has not deterred many potential decipherers from offering their own interpretations. Indeed, more has been written about this Cretan inscription than about any other, but the majority of works are pure fantasy.

In this work a three dimensional geometric model of the Phaistos disk was developed using three dimensional scanning technologies. On top of the advantages the 3d reconstruction of artefacts have, the digitization of the Phaistos disk can also be employed in education and in presentations and familiarization with the disk of students, scientists and heritage enthusiasts over the internet. Such a project is under development at the moment, in collaboration with the Dennis Gabor College in Budapest, Hungary.

This work was performed during an internship placement in the Laboratory of Precision Machining and Reverse Engineering (PMRE Lab) of the Mechanical Engineering Department, at the Technological Education Institute of Crete. Internships are widely considered a vital part of a modern education curriculum. An increasing number of students and companies are becoming aware of the beneficial experiences obtained during them. Students increasingly demand such programmes to acquire professional skills and become self-sufficient and motivated, while at the same they are identifying career paths (Vairis et al. 2014). The PMRE Lab provides such capabilities to its students, with opportunities to its students to work with state of the art equipment and technology related to numeric control machining processes, 3d printing, 3d scanning and reverse engineering. This work is a successful example of a laboratory intern working in 3d scanning and reverse engineering for heritage applications.

Methodology

The 3D shape acquisition technologies used for cultural heritage digitization can be broadly divided into two categories: laser-based methods and image-based methods [11]. The former can identify 3D shapes from archaeological artefacts with high accuracy in texture, colour and geometry. Due to the rapid advances in computing, this is becoming increasingly popular both in research and in practice. The accuracy and resolution of the structured-light methods rely heavily on the light pattern projected onto the subject, while those of cameras such as the Konica Minolta VIVID 900/910, used in this study rely on triangulation.

In this study, the advantages of stereoscopic method are used and the efficiency is improved by automating the camera calibration. On the other hand, to increase the resolution of the reconstructed model, much attention was also paid in dividing the disk into separate areas. This was necessary in order to scan each area with low focal length lens, which provide more accurate texture results of the scanned surfaces (Hua at al. 2010).

A line scan camera has several advantages over an area camera in digitizing cultural heritage artefacts. It provides higher spatial resolving capability, which makes it more suitable for finer details; secondly, it is able to record colour information with improved fidelity. Furthermore, it has lower geometric distortion, thus producing high accuracy geometric shapes. Finally, in contrast to an area camera, pixel interpolation is never involved in a line scan camera (Ramanath et al. 2002).

In order to produce the digital three-dimensional geometric representation of the Phaistos disc in the computer, an accurate replica of the disk with respects to the shape, size and texture, by Vasilis Politis 'Spirit of Greece" potter was employed. This was 3d scanned with the non-contact 3d laser scanner Konica Minolta VIVID900/910 (fig. 1). The Konica Minolta VIVID900/910 3d non-contact laser scanner is operating using reverse triangulation. With this method a thin light beam is projected on the scanned subject and the reflection from the surface of the part is captured through the lens of the camera. During each scan, a finite number of points is produced to capture the object’s geometry. In the cloud of points captured during each scan, geometry data in the form of Cartesian coordinates and texture data in the form of Red Green Blue colour code data are stored (Pavlidis et al. 2007).

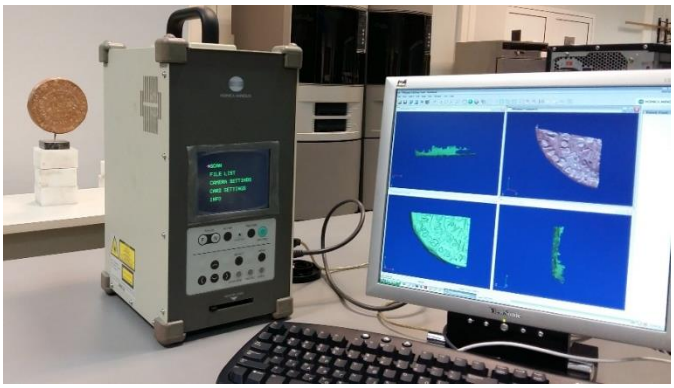

Figure 1: Scanning the Phaistos disk

The camera software tool “Polygon Editing Tool” was used for the production of an accurate digital copy of the Phaistos disc geometry from the cloud of points. For the synthesis, processing and exporting of the three-dimensional surface model the Geomagic Studio software tool was employed. The steps followed are:

1) Preparation of the scanning environment
2) Scanning
3) Composition and Processing of the Point Cloud and the Polygon Mesh of the Phaistos disk
4) Surface Model Extraction, Texture and Colour

With this process, a high detail digital 3d geometric surface model of the Phaistos disk was produced from a finite number of point clouds, which were captured with a reverse engineering camera, during multiple scans taken of the replica disk.

Results

Preparation of the scanning environment

The environment where the scans were taken was set to isolate each unnecessary object and colours from the background of the workspace, since such distortions degrade the results. Therefore, an appropriate white cloth was placed as a background, which does not reflect the incident radiation from the laser beam with an ambient light.

The ambient light is also a major factor in the correct mapping of the object geometry, because the scan quality is highly affected by the environment and scanned object shadows. For this reason, several tests were conducted to determine the appropriate lighting during the scanning process in order to achieve better scanning results, with minimized gaps and noise in the scanned data.

Scanning

For the detailed modelling of the Phaistos disc it was necessary to take nine (9) different scans of each side, in addition to the lateral and bottom views, producing twenty-one (21) scans in total. Scans were taken, using the camera lens with 25mm focal length (fig. 2). This was necessary, in order to capture as accurately as possible the Phaistos disk details, texture and colour.

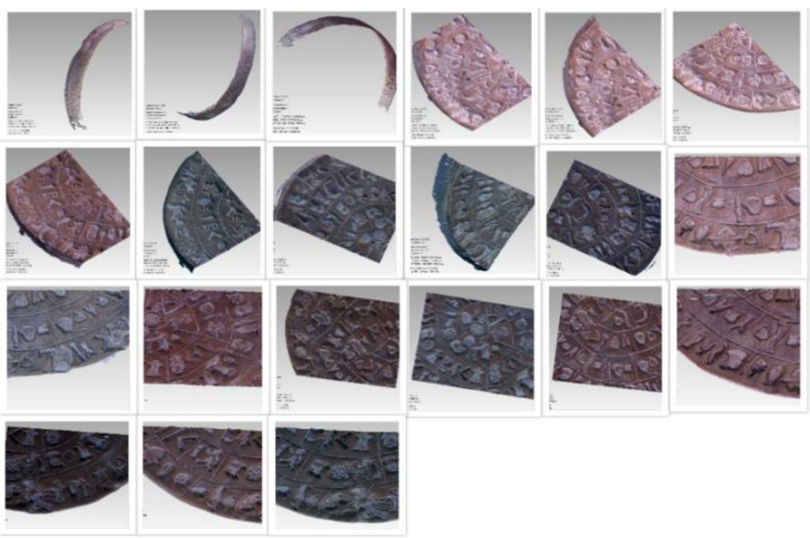

Figure 2: Individual scans taken from the Phaistos disk

Composition and Processing of the Point Cloud and the Polygon Mesh of the Phaistos Disk

Each point cloud from each scan was exported in stl geometry file format from the camera Polygon Editing Tool software. These files were imported to the Geomagic Studio software tool for the synthesis, processing and exporting of the three-dimensional surface model of the Phaistos disk.

The next step was to manually select identical n-points from each two successive scans and match them, in order to correctly orient the scans, with the manual registration process (fig. 3). This process was used in all scans taken of the Phaistos disk. This resulted in coupling all neighbouring point clouds and ultimately in the three-dimensional geometric model of the copy of the Phaistos disk.

Figure 3: Phaistos disk registration process, by matching equivalent points between two successive scans.

To minimize any deviation between the points that were selected with the above procedure, the Global Registration method was applied which automatically synthesizes the selected points. This process automatically and without user intervention, further reduces the distance of the aforementioned selected points and increases the accuracy of the developed geometric model (fig. 4). In order to apply this automated process, a manual registration process must be implemented first to correctly orient and put together all the scans of the geometric model.

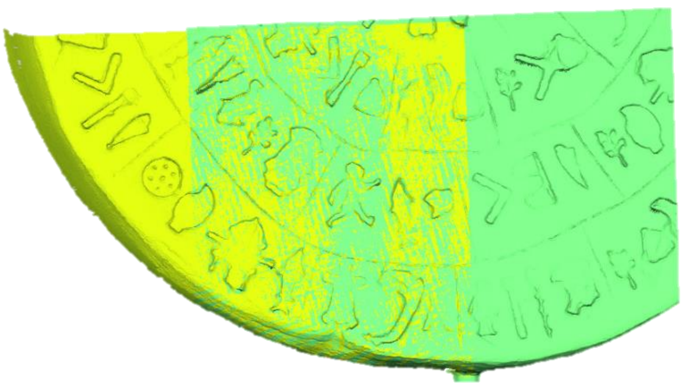

Figure 4: Result of the automatic registration process

An important step in this process was the merging of the overlapping points, to produce the final polygon mesh of the Phaistos disk. At this point during the polygons process phase, it was necessary to exploit the complete cloud of points in critical areas of the Phaistos disk, in order to more accurately represent fine geometrical details.

The final step was to fill small discontinuities, which could not be automatically processed during the conversion of the point clouds into the polygon mesh. These discontinuities were probably due to areas with noise or gaps in the point cloud itself. Also, other issues in the polygon mesh, such as random polygons or polygons with indeterminate shape, were automatically removed from the polygon mesh (fig. 5).

Surface Model Extraction, Texture and Colour

The surface model extraction was implemented in three stages, based on the polygon mesh. Initially it was necessary to define and manually design the boundaries of the grid that defines the polygon geometry profile (fig. 6). In this process the automatic tool was not used to place the limits, because of the complexity of the shapes on the Phaistos disk at the back and the front view.

Figure 5: Final geometry of the polygonal Phaistos disk mesh, after eliminating overlaps, editing discontinuities and redirecting the polygons

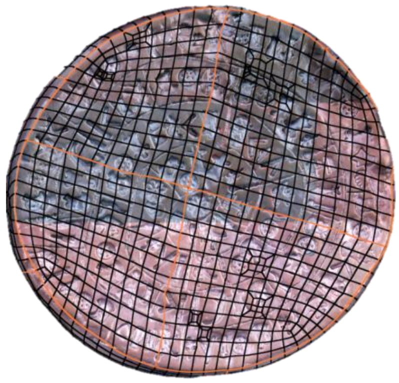

Figure 6: Manual application of limits to the Phaistos disc surface to adjust the grid from which the 3d geometric model of the Phaistos disk surface was developed

The second step was the definition of a grid which would form the final surface geometry of the polygonal mesh (fig. 7). For this purpose a sufficiently dense grid was developed, in order to map the finer details on small area surfaces. Auto correction filters were also applied to the correct arbitrary intersections between adjacent edges of the grid, on critically thin areas.

In the third step of the surface geometry construction process, an adaptive method was employed, to refine the surface model geometry, considering the parameters shown in table 1. Figure 8 shows the resulting geometry of the above procedure and in Table 2 the number of points in the cloud and the number of triangles considered in the Phaistos disk polygon mesh before and after the merge process are shown.

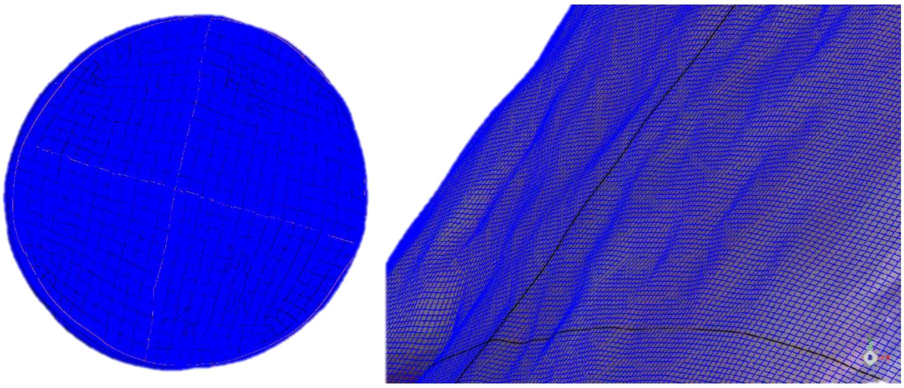

Figure 7: Detail from the schematic representation of the grid around the Phaistos disc

Table 1: Parameters employed in the adaptive surface extraction method

Maximum Control Points	Tolerance	Surface Tension	Outlier Percentage
100	0.00018 [mm]	0.0	0.5

Table 2: Polygons and points before and after processing

Patches (After Merge)	Number of Triangles (After Merge)	Current Points (After Merge)
1.578	2.504.046	1.305.606
-	Current Triangles (Before Merge)	Current Points (Before Merge)
-	4.657.672	4.495.475

The final step for the Phaistos disk model was the application on the disk surface geometry of the correct texture and colour, captured during scanning. The Phaistos disk texture and colour were extracted from the point clouds in the appropriate texture file format. To determine the correct texture and colour, the colour code of a selected surface close to the actual colours of the disc was initially considered. Selecting the area that approximates as closely as possible the actual colours of the disc was not an obvious process, because of the hidden areas on the geometry, as the position and density of the light source was constantly changing during the scans. This produced constantly changing shadows on the disk surface and thus the intensity of colour in the Phaistos disk surface was continuously changing, producing different colour tones on the surface from scan to scan.

Therefore, to find the exact colour code of the actual Phaistos disc, a part of the scan area with a colour close to the actual colour of the Phaistos disk was sampled, as shown in figure 9 and on table 3. To determine the prevalent colour in this area the Colour Code Picker software tool was employed.

Applying this method throughout the disk, it became obvious that no common colour can be identified in all the Phaistos disk areas. Applying the dominant colour in all of the Phaistos disk surfaces gives a not acceptable result shown in figure 10. Therefore, it was necessary, to extract an unaltered colour map and texture from the point cloud without any processing and changes in the RGB values throughout the Phaistos disk.

Figure 8: Final 3d geometric surface model of the Phaistos disc

Figure 9: Detail of the Phaistos disc surface during the scanning process where the colour depicted approaches the actual colour

Table 3: RGB colour values of a Phaistos disk surface sample and the prevalent colour value of that sample

Sample	Colour Sample	Red	Green	Blue	Sample	Colour Sample	Red	Green	Blue
1		234	194	205	7		204	172	183
2		246	214	229	8		212	177	190
3		182	144	158	9		188	156	172
4		206	162	174	10		252	220	220
5		204	166	159	11		233	194	205
6		218	174	179					

More specifically, after the completion of the surface model the polygon mesh was exported in .obj file format which stores texture information for each polygon in the mesh. In figure 11 the result of this process is shown. It is obvious that the differences in the lighting and shadows during the scans are captured in the Phaistos disk model at this stage. To complete the process, it was necessary to normalize the texture throughout the Phaistos disc, by recovering as much as possible of the colour contrasts between the individual scans. For this purpose, adjustments were made to the brightness and colour intensity of the model texture, using appropriate logarithmic filters (Gamma Correction) (table 4). The final 3d geometric model of the Phaistos disk developed is shown in figure 12.

Discussion

This is the first attempt to develop a 3d geometric model of the Phaistos disk with a computer. The result is for archaeologists or linguists to evaluate, but from the mechanical engineering point of view it is technically adequate and complete.

Figure 10: Monochromatic disk representation with the dominant colour applied in the Phaistos disk surface.

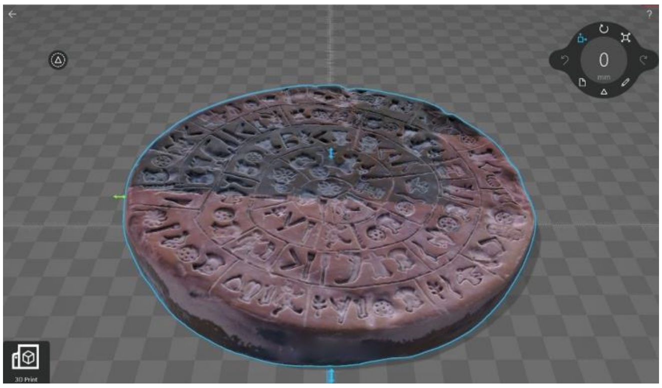

Figure 11: 3D virtual representation of the Phaistos disk with texture and colour.

Table 4: RGB colour values employed to the surface texture logarithmic colour correction method.

Gamma Correction		
Red	Green	Blue
4.0	1.0	0.9

Figure 12: Final 3D virtual representation of the Phaistos disk with texture and colour after the application of the logarithmic colour correction process

With the infrastructure used in this work, this has the finest detail possible. This result is adequate by current standards, judging by the size of the point cloud produced which is sufficient for the clear representation of the finer details of the Phaistos disk signs.

The surface texture was captured from the point cloud and it was processed in order to provide a result as close as possible to the real object. As expected the texture is constantly changing in the clay surface of the Phaistos disk and a different study with more advanced equipment in this field is required for a more accurate representation of the surface texture of the Phaistos disk in a 3d geometric model.

The developed model preserves the Phaistos disk shape in time and it can be exploited for documentation, visualization, reconstruction and education purposes through different means, such as the Internet, multimedia applications, presentations, etc. It also contributes to the preservation and the promotion of the cultural heritage, which is critical for its history, but also for areas, such as tourism, that highly contributes to the country’s economy. Similar efforts with other artefacts would further contribute in this direction and would be very welcomed.

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