

# Digital Modeling of Monument of Queen Khentkawes

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## Abstract

Giza Plateau Mapping Project (GPMP) directed by Egyptologist Dr. Mark Lehner achieved digital modeling of *the monument of Queen Khentkawes*, as known as the fourth pyramid in Giza, in 2007. As members of GPMP, the authors report how this digital modeling was done. First, the monument of Queen Khentkawes was scanned by laser radars with 5[mm] mesh accuracy in average. Some parts of wall of the monument on which hieroglyphs appear were scanned separately with a very high-accuracy (0.1[mm] mesh) laser scanner. Second, these scanned raw data were combined, aligned, and integrated into complete 3-D geometry model on a computer. Finally, computation of volumes of the monument was done from the geometry data of the monument, so that archaeologists could use for investigating relationship among the monument and Great Pyramids, Sphinx, and other temples around Giza Plateau.

## 1. Introduction

Giza Plateau Mapping Project (GPMP) directed by Egyptologist Dr. Mark Lehner aims construction of three-dimensional model and positioning of the exact location, in terms of UTM world standard coordinate system, of structures on Giza Plateau.

Through 2006 to 2007, *the monument of Queen Khentkawes* (the monument hereafter) shown in **Figure 1** was focused on. Three-dimensional shape model of the monument was obtained and is to processed for further application.

The location of the monument was positioned on UTM map whose reference coordinate was given by other research done by Birmingham University in 2003.



**Figure 1:** The monument of Queen Khentkawes

## 2. Methodology and Equipments

Laser radars and laser range finders are widely used to obtain three-dimensional shape of structures. Since laser radars and laser range finders are not able to fully cover the surface of the monument, scanning must be done part by part, area by area. Those scanned surfaces are to be integrated into a single three-dimensional model eventually by post-processing on computers.

During laser scanning, several (normally 10 to 100) points on the structure are specially marked and scanned by laser radars for integration of separately scanned surface. These marked points are often used to position the structure by Global Positioning System (GPS).

The authors used a couple of different types of laser radars and a single type of laser range finder (mentioned later). The authors processed all scanned data and integrated into a couple of shape models which are to be integrated into a single model eventually.

The following equipments were used for positioning and three-dimensional modeling of the monument.

#### *Global Positioning System*

Trimble R7.

#### *Laser Scanners and Markers*

Riegl LPM-Z420 laser radar:

- Shape measurement method: laser radar (time of flight).
- Texture scanning method: digital camera (Nikon D100 with 14mm F2.8 Fisheye lens) fixed on top of the scanner.
- Measurement range: approx. 2[m] to 1,000[m].
- Maximum resolution: approx. 1[mm] to 10[m] (minimum step of rotation is 0.008[deg], beam diameter is 0.2[mm]).
- Range accuracy: 5[mm].

(LPM-Z420 was used for scanning of exterior walls and 2nd roof of the monument.)

Riegl LPM-25HA laser radar:

- Shape measurement method: laser radar (time of flight).
- Texture scanning method: built-in color sensor.
- Measurement range: approx. 1[m] to 60[m].
- Maximum resolution: 8[mm].
- Range accuracy: approx. 10[mm].

(LPM-25HA was used for scanning of interior walls and top roof of the monument.)

Konica Minolta Vivid 910 laser range finder:

- Shape measurement method: laser triangulation with built-in CCD digital camera.
- Texture scanning method: built-in CCD digital camera.
- Measurement range: approx. 70[mm] to 5[m].
- Maximum resolution: approx. 0.2[mm].
- Range accuracy: approx. 0.1[mm].

(Vivid 910 was used for scanning of hieroglyphs on jambs in the monument.)

Laser markers: Retroreflectors which have cylinder shape of 50[mm] diameter were designed as laser markers and used for post processing (data integration) of laser scanning. The number of the markers distributed over the monument was 43.

#### *Computer Software and Hardware*

InnovMetric Polyworks version 8 and version 9 were used for overall data processing of three-dimensional shape model. Riegl Riscan Pro was also used for intermediate part of data processing. (They were run on Intel Core 2 Duo laptop PC (Microsoft Windows XP) with 2GB RAM.)

A special in-house software named *Sphinx* has been developing by the authors for archaeology-quality printing (e.g., 1/50 scale) of point-cloud model and also for further applications including computation of volumes. (The Sphinx was run on a Mac (Intel Core Duo laptop, Mac OS X 10.4) with 2GB RAM.)

### 3. Global Positioning and Laser Scanning Survey

Global positioning of laser markers distributed on the monument and laser scanning survey (3-D modeling) of the monument had been done through 4 Dec. 2006 to 21 Dec 2006.

### 4. Data Processing

Data processing of the 3-D model of the monument has been done as follows.

#### 4.1. Aligning, Merging, and (not) Integrating Point-clouds

Since the laser scanning was done part by part, the scanned data (point-clouds) must be integrated into a single model. First, positions of each scanned point-clouds were aligned precisely by using laser markers distributed on the monument. Fine tuning of alignment was done by ICP (Iterate Closest Point) algorithm.

Second, aligned point-clouds were merged into a single point-cloud model. In this process, duplicated points and noise were eliminated. In computer science, merged point-cloud are often processed to equalize density of points over the scanned surface, mostly for making beautiful computer graphics. This equalizing process is called integration. The authors decided to skip integration process of the point-cloud since the integration process likely hides some detail of scan.

Screenshots and computer-graphic fly-through animations of merged point-clouds were made by using combination of Riscan Pro and Polyworks.

#### 4.2. Printing Point-clouds

The authors has been developing a special software named *Sphinx* for printing point-clouds. The current version of *Sphinx* allow users to see three-dimensional view of pointcloud with scaled grid and to make orthogonal projection of point-cloud onto a two-dimensional horizontal plane (as a plan) and vertical plane (as a section).

The current version of *Sphinx* is capable to import ASCII (text) point-cloud data, point-cloud data with intensity (grayscale value), and point-cloud data with color. It is also capable to export the projected point-clouds to a PDF file, which is resolution-independent (that means you can have huge image of point-clouds) and editable by appropriate PDF editor like Adobe Illustrator.

The current version of *Sphinx* runs on Apple Computer's Intel-based Macintosh computers with Mac OS X 10.4.8 (as known as Tiger). The future version of *Sphinx* will allow users to cut any bounding volume (normally a thin slice) out from whole bounding volume of given point-cloud.

### 5. Results

Results of scanning are shown in **Figure 2** to **Figure 6**. Precision of these three-dimensional models ought to be in range of 5[mm] to 10[mm]. Accuracy of these models has not been examined.

**Figure 2** shows bird's view of the monument by pointcloud rendering of the 3-D model.

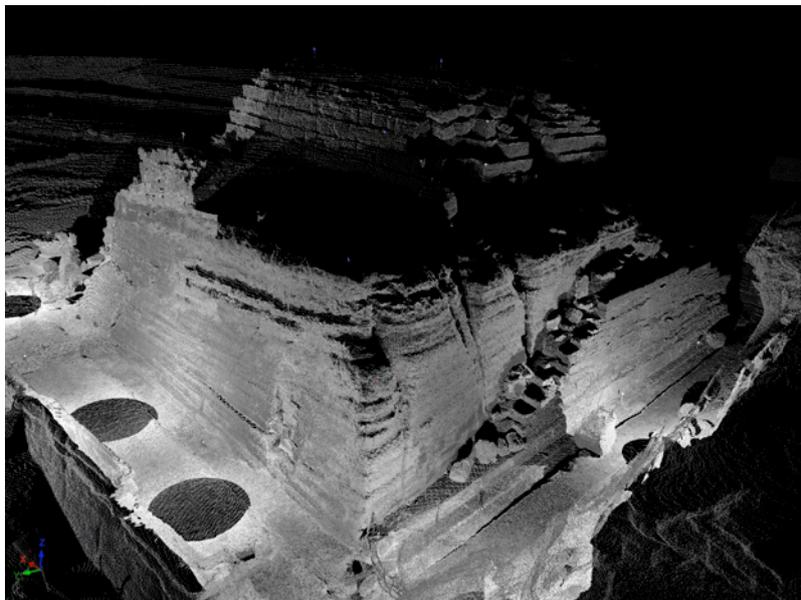
**Figure 3** shows vertical orthogonal view of the monument by texture-mapped computer graphics. Note that orthogonal view is hardly obtained by conventional photograph.

**Figure 4** shows top view of the monument, including inner structure of the monument completely aligned to the exterior.

**Figure 5** shows floor plan of the inner structure of the monument.

**Figure 6** shows an example of hieroglyph found on the wall of the monument in 3-D computer graphic rendering.

Note that archaeologists cannot change lighting condition of conventional photograph of such hieroglyphs, however, they can change the lighting to get better view with 3-D computer graphics.



**Figure 2:** Point-cloud rendering of the monument

## 6. Discussion

The three-dimensional modeling of the monument of Khentkawes has been achieved. Several regions of the monument which were hard to scan had still been left blank. We must wait for development of new apparatus to digitize shape of such regions since any other laser scanners available at this moment seem not to be good enough for such scanning. Post-processing approach of filling such holes might do the trick, hopefully.

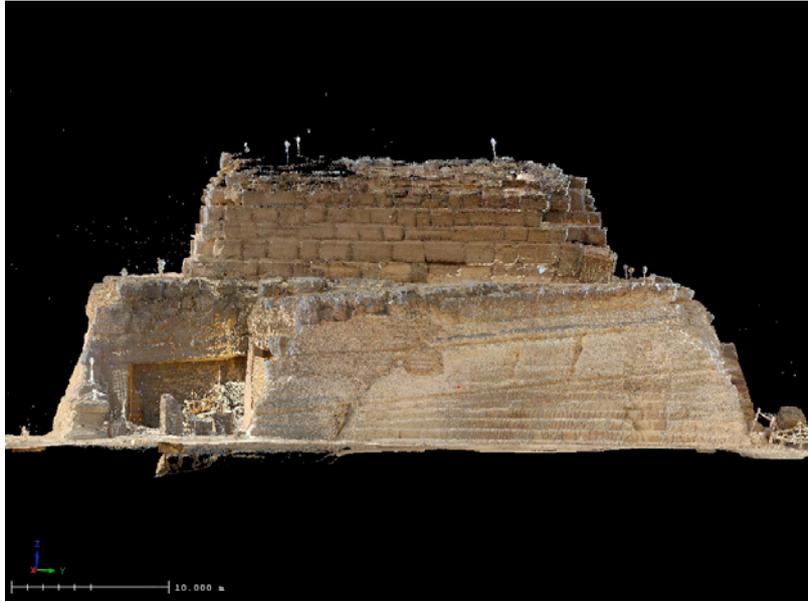
Accuracy of three-dimensional models have not been examined. Comparing distances between arbitrary two points of digital model (three-dimensional point-clouds) and physical model (actual monument) would give us some hints on accuracy of the digital model.

Sphinx, an in-house software dedicated to archaeology use was born and has been in development phase. Sphinx processes and renders point-clouds image with resolution independent way. This means, the scanned model can be printed out in very high resolution like, say, 1,200[dpi].

## 7. Concluding Remarks

The GPMP has achieved positioning of the monument of Khentkawes and three-dimensional modeling of the monument including the chapel and the chamber inside the monument. Each laser scans have been integrated into a single model.

From this 3-D model, materials for archaeological inspection can be derived. The authors believe that the 3-D model of cultural properties would be the most fundamental material for further inspections.



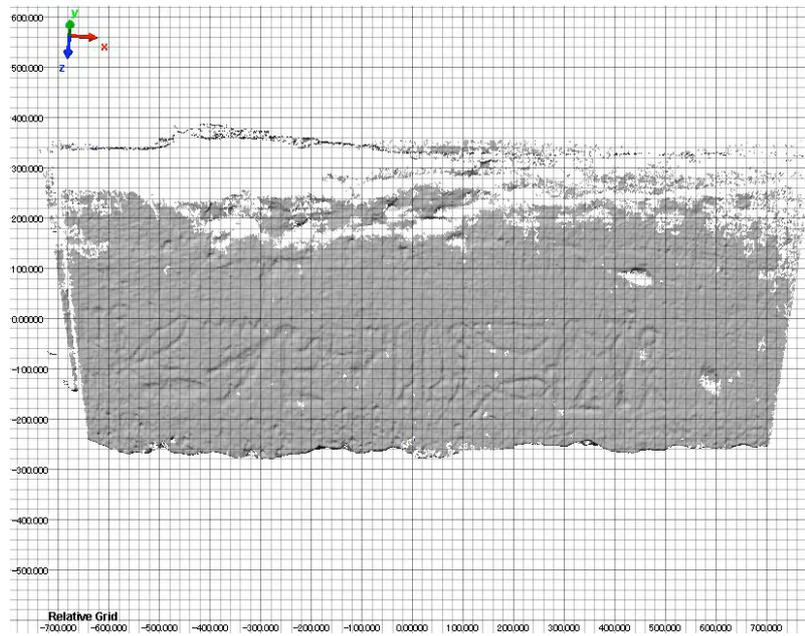
**Figure 3:** Texture-mapped image of the 3-D model of the monument



**Figure 4:** Top view of the monument (including inner structure)



**Figure 5:** 3-D model of inner structure of the monument



**Figure 6:** 3-D model of hieroglyphs on the monument