AT WORK SPECIAL

TOPCON

Saqqara Pyramid Laser Scanning Project

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Revolutionizing Archaeology with the Latest Scanning Technology

Scanning for clues - Recording the mysteries of a 4600-year-old pyramid

Surrounded by the Sahara, the step pyramid built by the king Djoser is the oldest pyramid in Egypt, built some 4,600 years ago. Two machines on tripods were facing the pyramid, while a man cautiously rappelled down its steep slopes with an arm-spread equipment, like the wings of Icarus, on his back. More than 20 people stood watching, with computers and transceivers at hand. This is not the typical excavation where artifacts are discovered, uncovered gently with camel hairbrushes. A 21st Century approach to archaeological research using cutting-edge technology - that, is what this project is all about. Using the latest laser scanning technology, the goal of this project is to capture detailed 3D measurements of the pyramid. The stars of this project were Topcon's laser scanner GLS-1000 and Develo Solutions' own laser scanner "Djoser."

Records of the Original State Supporting Future Research

This project began with the request from Dr. Zahi Hawass, secretary general of the Egyptian Supreme Council of Antiquities. Upon receiving the archeological request, laser scanning director Yukinori Kawae of Ancient Egypt Research Associates Inc. (AERA) said, "A few stones have fallen from the pyramid, leaving fear for more damage. This is what triggered us to start this project.

"Restoration went into action right away, but the problem was that the original state of the structure could be lost forever due to restoration. That's why it was decided that we record the actual state of the pyramid before restoration commenced."

Egyptian archaeology often brings an image of treasure hunts; however Kawae said the most important task in archaeology is to accurately record the actual state of monuments as they are discovered.

"It is true that still today excavation in Egypt is often misunderstood as treasure hunts. Egypt has been a civilization of "treasures" - images brought by items such as the golden mask discovered from King Tutankhamen's tomb gives such a strong impression so that "to find things" is placed center stage, leaving the basic archaeological tasks of keeping record unfortunately undervalued."

The methods in recording historical sites have been limited in the past. Information that

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photographs and drawings could retain were only a fraction of those available at archaeological sites. Artifacts can be stored and archived, but the actual sites are destructed through excavation, resulting in the loss of the information that once existed. Laser scanners can contribute to solve this dilemma in archaeology.

Laser Revolution in Archaeology

"Laser scanners can collect 3D data of archaeological sites, which give us enormous amount of information in comparison with those we can obtain from photographs and drawings. Even if the original information of sites are lost from restoration, 3D data allows future researchers to analyze and study them as if they were actually at the sites themselves," Kawae explains.
With laser scanning technologies, a Japanese team achieved the production of a detailed 3D model of Queen Khentkawes' tomb in Giza and a temple at Kharga Oasis in collaboration with AERA. These attainments prompted Dr. Hawass to request AERA, led by a leading American archaeologist Dr. Mark Lehner, to use Japanese technologies to conduct 3D scans of the world's oldest pyramid.
However, this step pyramid is much larger - approximately tripling in height - than Queen Khentkawes' tomb, making it that much harder to scan. The experience of the Japanese team in use of the latest high performance laser scanners, and a fruitful collaboration between archaeologists and scientists ensured the project's success.
The team included Dr. Kosuke Sato from Osaka University, a firm believer in the need of 3D measurements data in archaeology; Dr. Hiroyuki Kamei, the team leader of Khentkawes' tomb 3D laser survey of the Tokyo Institute of Technology; Dr. Ichiro Kanaya of Osaka University who analyzed the tomb scan data, and; Dr. Tomoaki Nakano, an associate curator of the Ancient Orient Museum.
Laser scanners from Topcon and Develo Solutions were chosen as the appropriate equipment for the project.

Scanning the Pyramid every 5mm

Topcon's GLS-1000 laser scanner can scan 3,000 points per second at sub-five millimeter precision from a distance of 100 meters. The defining difference between Topcon's GLS-1000 and other laser scanners is that Topcon originated the "Precise Scanning Technology." The "Precise Scanning Technology" minimizes noise and replicates a realistic and accurate texture of the scanned object.
Even with this latest technology, the GLS-1000 cannot fully scan the pyramid from the ground. The step pyramid reaches 60 meters in height, and the steps create blind areas. To scan these blind spots, a piece of equipment was needed to scan from the top of the pyramid moving down.
In a preliminary inspection, Takaharu Tomii of Develo Solutions climbed the pyramid and realized the pyramid was larger than what he had expected. Use of a helicopter was first considered to scan the pyramid; however Kawae specified that the scans must be conducted in 5mm increments.
Even though he had experience scanning numerous

Kosuke Sato
Osaka University

Hiroyuki Kamei
Tokyo Institute of Technology

Yukinori Kawae
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structures in the past, Tomii had never taken measurements at such precision. Then, the idea came. "I called a rock climbing survey specialist, and asked him 'Can you climb pyramids?' The answer I got was '*What?*' " Tomii said, chuckling at the memory.

After returning to Japan, Tomii designed and developed the outstretched equipment just for this pyramid project. Named after the king for whom the pyramid was built, Djoser had arms stretched five-meter long, with four scanners and six CPU boards to process the scanned data installed on it. This configuration enabled the team to scan 40,000 points every second with sub-five millimeter precision. Tomii planned for Djoser to be worn on the climber's back, where he would rappel down the sides of the pyramid, scanning as he makes his way down.

With the equipment and the plan to scan the pyramid from both the ground and the top, the preparation for the first-ever project was now completed.

Battling the Heat and Sand

In June of 2008, the combined team of AERA, Osaka University, Tokyo Institute of Technology, Ancient Orient Museum, Topcon and Develo Solutions had gathered in Saqqara with equipment weighing about 900kg.

Despite all of the preparations, the scanning project encountered one problem after another. The Topcon GLS-1000 unit was a prototype and had not been developed for protection against desert heat and sand. In preparation against the heat, Katsunori Tomita of Topcon Corporation had purchased massive amounts of semi-adhesive cooling gel pads, normally used to lower fever in children. The gel pads were placed on the scanner, inside a hand-made cooler sheath for the GLS-1000 that Tomita had created using foil insulation sheets purchased at a crafts store in Japan. He dubbed the make-shift apparatus a "cooler suit."

It turned out that even before having to worry about overheating, the two GLS-1000 scanners were not configured to align with the project's requirements. From the desert, Tomita called engineers in Japan and after hours of international calls, Tomita had successfully configured the GLS-1000 to full operational status. From that point, the GLS-1000 scanned the pyramid without a single problem; the "cooler suit" and gel pads were effective beyond Tomita's hopes. Though a prototype, the GLS-1000 also proved its environmental durability against sand and dust.

On the other hand, Djoser also had its own trials. Hoisting up the 30kg system to the top of the pyramid - being careful not to hit the steps - was enough hassle, but the sand and heat also created problems.

Tomii laughs as he recalls "The display cracked from the heat, sand had jammed the fan and wouldn't move, it was just a parade of problems from the start. Sand caused the touch keys to get stuck after we punched in anything. Cords broke. And, we ended up using the soldering iron that we joked would be the end of our world if we had to resort to … on the very first day."

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The climbers had their share of problems as well. Rappelling down the pyramid with Djoser on their backs at constant speed was not an easy task. Especially having to be careful to keep the wings parallel to the pyramid slopes, the heavy equipment plus the weight of the power cords did not make the descent easy, by any measurement.

Mobile scanning system "Djoser"

It was a tough one even for professional climbers: two climbers climbed and descended in turn, ten times a day for three weeks. Kawae said, "The only thing the ground staff could do while the two repeated the climbs was to listen to their hard breathing through transceivers."

Massive Measurement Data; Too Large for the PC

The file sizes of the data collected were much too large to fit onto DVD-ROMs, and the data exchanges had to be done in hard disks. Analysis of the scanned data was conducted by Kanaya, the 3D data expert. Surfaces are created from the point cloud data collected by the scanners, but there were more than 600 million points from the GLS-1000 data alone. Even for the seasoned professional, Kanaya had never handled a data set of this size. "The data set in total was about 200GB, and took hours just to read it," he said. "My computers at the university couldn't calculate the volume or the profile; we had to write a new program for the software to process the data. I believe a data set of this size is rare even in the world."

Why is there a need for such an austere data set that is beyond current technology? Sato answered, "That's because the 3D data is for the future. 3D data of historical sites and monuments were once regarded as supplementary data to provide the full view of the surrounding. But with continuous improvement of 3D technology laser scanners now acquire precise 3D data which can be used for

Ichiro Kanaya
Osaka University

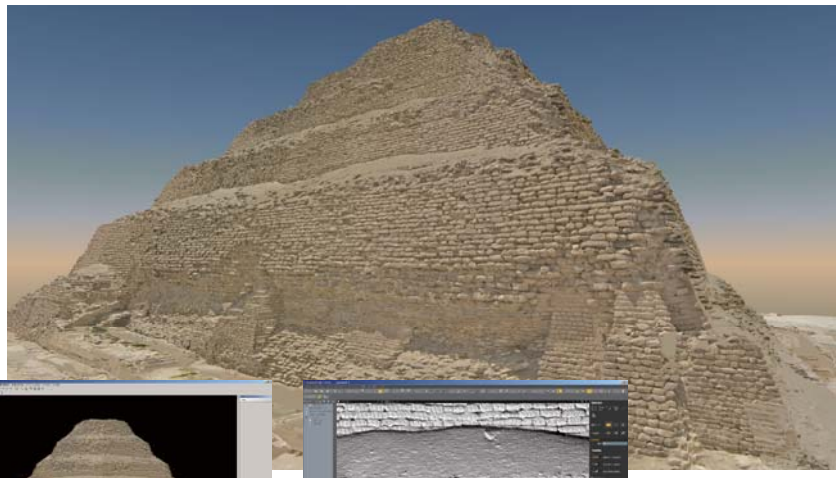
Tomoaki Nakano
Chubu University

Takaharu Tomii (Left)
Toshikazu Kameoka (Right)
Develo Solutions

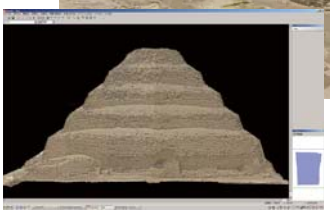
archaeological analyses.
He continued, "Since technology continues to advance, it is our duty to collect the most precise data possible. Although the data may be too large to handle now, it will be manageable in a few years' time."

The future of archaeology with laser scanning

Unlike computer graphics, the 3D images rendered from the scans show original textures of the stones. Details of the 3D images can be viewed from various angles zooming in and out from extreme close-ups to a bird's-eye view.
How can 3D data such as this one actually be used for pyramid researches? "It is said that the origin of the pyramid is the rectangular 'mastaba' tombs, and that the step pyramid is an evolved form with six mastabas stacked up. The 3D data may give us the clue to verify this theory," says Nakano, an Early Dynastic Period researcher. "By carefully studying the construction details and treatment of mortar treatment from the 3D data, we will be able to investigate many questions that we weren't able to confirm in the past."
"In archaeology, researchers' interpretations and objective descriptions tended to be mixed up. When we verified another researcher's hypothesis, it was rare that to find the hypothesis to be objective description." Kawae said, "If this 3D data is shared by researchers around the world, then leaving such precise information allows for open discussion. I believe that archaeology needs such sharing of information and open discussions, and this project will hopefully be the stepping stones for that to come true."
As the leader of introducing cutting edge technology into archaeology, Kamei said, "The No. 1 problem in archaeology right now is that information is continuously lost. Excavation means that we are damaging the existing conditions. If we can collect data without digging, that would be a perfect solution with nothing being better than that. I believe that utilizing radar research and 3D measurements will become more important in future research. I see archaeology as integrated science, and would like to see a more scientific archaeology, including 3D measurements, to become more universal."
According to Kawae, 3D archaeological measurements will be carried out in numerous sites including the Pyramids of Giza and the Sphinx. In that sense, there is no mistake that this first-ever pyramid scanning project will become the model case to define the direction of Egyptian archaeology in the future.



Colored 3D point cloud model



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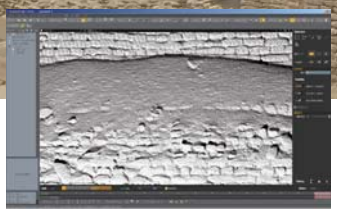


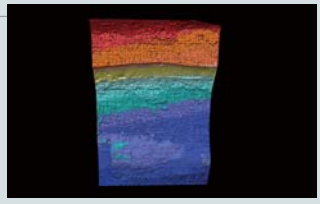
Reflection intensity map


Katsunori Tomita
Topcon Corporation


Kazuto Otani
Topcon Corporation

Mixing Archaeology and Technology

Modern archaeology stands upon technological advancements. Electrical resistivity survey, magnetometers and ground penetrating radars have been used within and out archaeology. These technologies have been developed during the Second World War for weapons such as maritime patrol aircrafts. After the war, European scientists had begun to use these technologies in the field of archaeology. The emergences of high-performance laser scanners have shown impressive outspread of archaeological recording of 3D data. Other than this Djoser's step pyramid measurement, Kharga oasis monuments research and Queen Khentkawes' tomb have also been measured using 3D measurement technologies by Japanese teams.



The Saqqara Step Pyramid

The step pyramid is the oldest pyramid built by the king Djoser in the third dynasty of Egypt. It is said to be built about 4650 years ago, 100 years older than the pyramids of the Giza Necropolis. Located 20 km south of Giza, Saqqara holds many tombs of royal families and nobility from the early dynastic period. Djoser's step pyramid is 60 m high, with the base measuring at 140m by 128 m with a 1.5 km wall surrounding the pyramid and nearby temples. Pyramids are a portion of an all-around religious facility; similar plans can also be seen in the pyramids in Giza.

Acknowledgements
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