

## RECONSTRUCTION WITH LASER SCANNING AND 3D VISUALIZATION OF ROMAN MONUMENTS AND REMAINS IN TYRE, LEBANON

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### Commission V, Working Group V/4

**KEY WORDS:** Laser Scanning, Cultural heritage, Reconstruction, Visualization, CG animation

### ABSTRACT:

3D scanning using laser scanners has been recognized as one of the most efficient and accurate way to record and reconstruct digitally large-scale cultural heritages. The authors report on 3D scanning survey of Roman monuments and remains in Tyre, Lebanon, which was conducted in September 2002, and on succeeded digital reconstruction and visualization of those monuments. During limited period of time for the survey, many Roman monuments and remains were scanned including the memorial gate on the paved road aligned by columns, a sarcophagus, and a stepped stand of the Hippodrome in Albaas area, as well as the whole excavation field in Ramali area and the interior space of underground tomb within the field, resulted in many sets of point cloud data. For 3D scanning, the authors combined two different types of laser scanners, one with coarser resolution with faster scanning speed and coverage, and the other with finer resolution with slower scanning speed. The former was mainly used to determine the location of individual remains or structures, while the latter was used to record the details of the monuments. By combining both scanners, larger areas were covered efficiently, while recording the details of important monuments. Then the data were automatically aligned and merged with a software, and the resulted polygon data were mapped with textures using digital photos obtained at the time of laser scanning. Finally, CG animation of those remains has been produced for providing photo-realistic spatial image of the remains to those who have never visited the place.

### 1. INTRODUCTION

Founded at the third millennium B.C. by Phoenicians, Tyre became to enjoy its golden age in the first millennium B.C. for its flourishing maritime trade across the Mediterranean Sea. However, Tyre was conquered by Alexander the Great in 332 B.C., and later on it fell under Roman rule in 64 B.C.

For several decades the General Directorate of Antiquities excavated in and around Tyre, concentrating on major Roman archaeological sites in the town, which can be seen today. In 1984 UNESCO declared this historical city and its monuments a World Heritage Site.



Figure 1. Tyre, the Republic of Lebanon

Since 1999 Nara University has made archaeological survey in Ramali Area of Tyre by the request of the General Directorate of Antiquities, the Republic of Lebanon, and discovered more

than thirty remains of Phoenician and Roman periods. In September 2002, joining in the archaeological survey of Ramali area by Nara University, the authors conducted laser scanning of Roman monuments and remains in Albaas and Ramali areas of Tyre.

The scanned objects included the memorial gate on the paved road aligned by columns, a sarcophagus, and a stepped stand of the Hippodrome in Albaas area, as well as the whole excavation field in Ramali area and the interior of underground tomb in the field (Figure 2, Figure 3).

The acquired point cloud data were automatically aligned and merged by a software, and the resulted polygon data were mapped with textures using digital photos obtained at the time of laser scanning. Finally, CG animation of those monuments and remains has been produced for providing their photo-realistic spatial images.



Figure 2. Albaas area (Left: Memorial gate on paved road, Right: A stepped stand of the Hippodrome)



Figure 3. Ramali area (Left: Excavation field, Right: The interior of underground tomb)

## 2. 3D MEASUREMENT BY LASER SCANNERS

### 2.1 Laser Scanners

Laser scanners measure the distances between the scanner and the points on surface of measured object by measuring the return time of laser beam emitted from the sensor. At the same time, horizontal and vertical angles of the laser beam are measured. As the result of combining the angles of the laser beam and the distances, 3D coordinates of the object surface are computed. Immediate outcomes of the laser scanners are point cloud data with 3D coordinates.

The authors used two types of laser scanner for the 3D measurement in the year, one with coarser resolution and faster scanning speed and wider coverage (LMS-Z210 of Riegl) and the other with finer resolution and slower scanning speed (Cyrax2500 of Leica Geosystems). The former scanner was mainly used to determine the location of individual remains or structures, while the latter scanner was used to record the details of the monuments and remains. By combining both scanners, larger areas were covered efficiently, while recording the details of important monuments and remains (Figure 4).

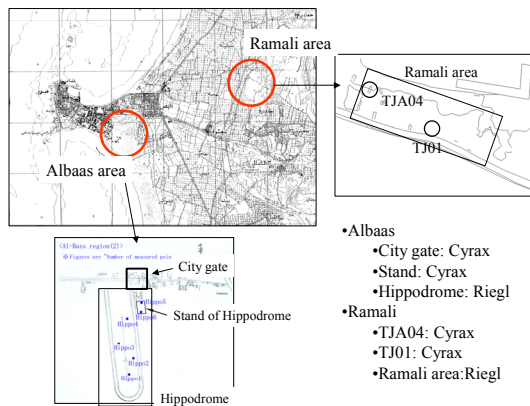


Figure 4. The measurement areas and scanners used

### 2.2 Generation of Polygon Data from Point Cloud Data

Laser scanning should be done from many different positions around the object in order to obtain the whole surface data of the object. In Tyre the scanning was done basically from on the ground except that the scanner was lifted up when the roof floor of the stand of Hippodrome was scanned. Therefore, for example, the upper roof surface of the memorial gate, which was about 20 meters high, could not be scanned.

The acquired point cloud data have to be connected with each other in order to reconstruct continuous surface of the object. All data obtained were aligned, or placed in right position, with PolyWorks, a product software of InnovMetric. After manual selection of three or four corresponding points, PolyWorks

aligns simultaneously all the point cloud data automatically by minimizing the sum total of positional errors between corresponding points among overlapping point cloud data.

After the alignment PolyWorks merge all point cloud data into one polygon data automatically. Then the data can be transferred to CAD, CG or VR software (Figure 5).

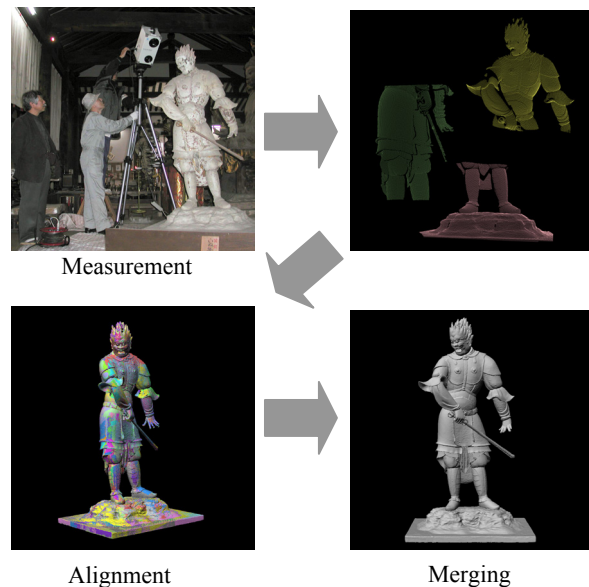


Figure 5. Generation of polygon data from point cloud data (The statue of Basara, Shin-yakushiji Temple, Narra, Japan)

## 3. LASER SCANNING WITH CYRAX SCANNER

### 3.1 Cyrax scanner

Cyrax 2500, though it has a limited scanning view with 40 degrees vertically and 40 degrees horizontally, have high accuracy in distance measurement and finer angular resolution. Distance measurement accuracy is less than 6mm and angular resolution is 0.04 degrees in maximum. Due to the limited viewing angle, considerable number of scans are sometimes necessary in order to cover the whole surface of the object, especially when the object is large or the space for scanning is narrow. In the sense, Cyrax scanner is more appropriate for obtaining more accurate 3D data of monuments and structures.

The scanning time depends on the number of points to be measured. When the detail of the object is necessary it usually takes that around 800x800 points are measured, whose scanning time is about 15 minutes.

By scanning with Cyrax2500, point cloud data with 3D coordinates as well as values of reflection rate of the object surface are obtained.



- Measurement range (min to max.) 1.5m to 100m
- Range measurement accuracy: <6mm
- Measurement frequency: 1kHz
- Reflectivity is simultaneously measured.

Figure 6. Cyrax2500

### 3.2 Laser scanning with Cyrax scanner

The laser scanning with Cyrax2500 was conducted for 7 days, from 15th to 21st of Sept. 2002. The numbers of scans achieved for each object were as follows;

Albaas area:

Memorial gate on the paved road aligned by columns

---46 scans

Stepped stand of Hippodrome---38 scans

Sarcophagus---3 scans

Ramali area:

Underground tomb TJ1---11 scans

Underground tomb TJ4---48 scans

The scanning was done basically from on the ground. However, when the roof floor of the stand of Hippodrome was scanned, the scanner was lifted up on the roof.

### 3.3 Alignment

The acquired point cloud data by the measurement with Cyrax2500 were aligned by the software PolyWorks.

The alignment basically does not need any target or marker because the software figures out corresponding geometry in overlapping portion among plural data and align them in correct position automatically. After manual selection of three or four corresponding points on partially overlapped plural point cloud data, the software calculates all point cloud data simultaneously, preventing accumulation of errors.

As the result, the point cloud data of the memorial gate and paved road, a stand of Hippodrome, a sarcophagus, and underground tombs called TJ1 and TJ4 were all aligned efficiently, and their 3D data could be dealt with on computers (Figure 7 to Figure 10).

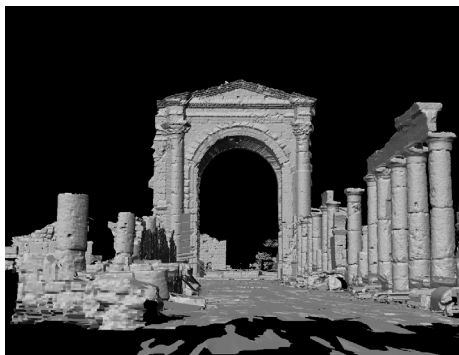


Figure 7. Aligned 3D data of the memorial gate on the paved road aligned by columns

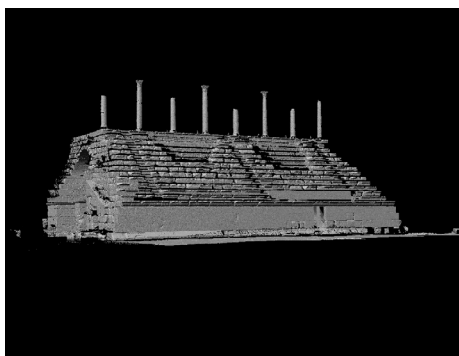


Figure 8. Aligned 3D data of the stepped stand of Hippodrome



Figure 9. Sarcophagus

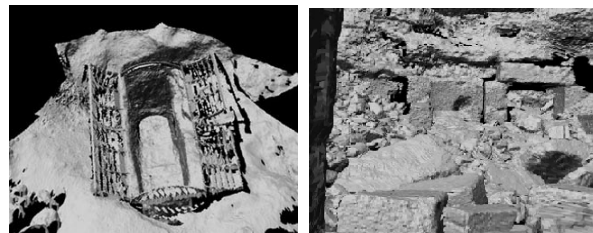


Figure 10. The entrance of the nderground tomb TJ1

## 4. LASER SCANNING WITH RIEGL SCANNER

### 4.1 Framework

The Riegl scanner was assigned to cover the large area of field and to achieve high efficiency in fieldworks of laser scanning. In order to identify reference tie-points in point cloud data easier and more accurate, reflection sheets were attached to the object surfaces and their 3D coordinates were measured so that they could be used as a reference points for the alignment of point cloud data (Figure 11).

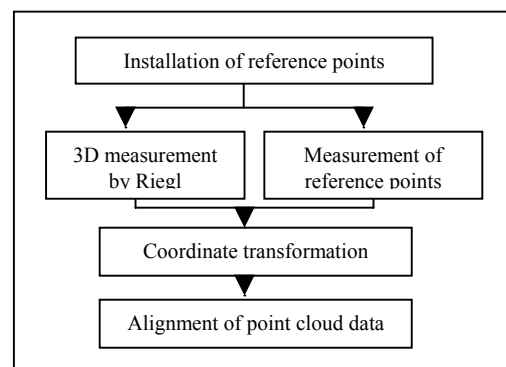


Figure 11. Framework

### 4.2 Riegl Scanner

Riegl LMS can yield panoramic range image with almost 360 degree horizontal range. The maximum measurement range reaches 300m. The accuracy in distance measurement is approximately 2.5cm and accuracy in angular measurement of laser beam is around 0.24 degree. Since the range measurement errors occur randomly when the Riegl LMS-Z210 scans completely flat plane, the outcome looks like bumpy plane with irregular errors. To remove such bumpy errors and to reconstruct smooth and flat plane, filtering techniques are indispensable. Riegl LMS Z-210 is better for covering wider area and recording of the locations and rough shapes of large archaeological structures such as columns and gates, and terrain topography around them.

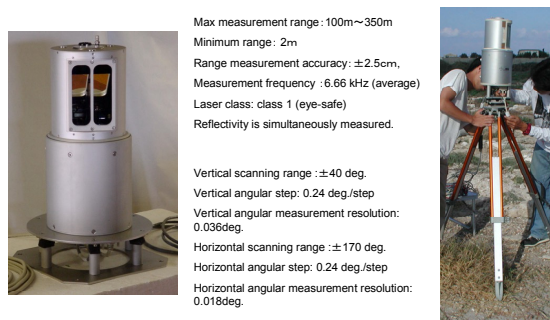


Figure 12. Riegl LMS-Z210

### 4.3 Laser scanning with Riegl scanner

The laser scanning with Riegl LMS Z-210 was also conducted for 7 days, from 15th to 21st of Sept. 2002. The objects scanned by the Riegl scanner included Hippodrome in Albaas area as well as the excavation site of Ramali area. Figure 13 shows an example of point cloud data obtained by Riegl scanner.

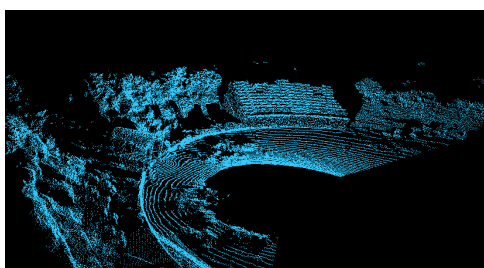


Figure 13. A point cloud data obtained by Riegl scanner

In the paper, the authors report on scanning of Hippodrom in Albaas area.

The number of measurement position in Hippodrome was 18, and the number of targets (reference points) was 57. The 3D coordinate values of all points were measured by a total-station (Figure 14, Figure 15).

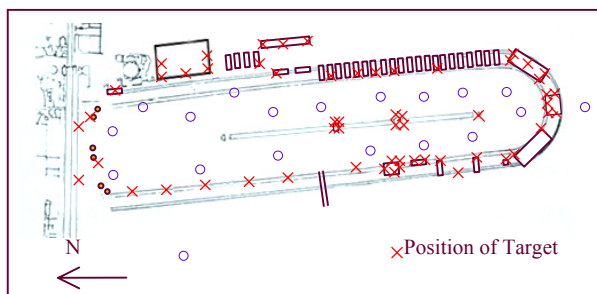


Figure 14. Position of scanning and target

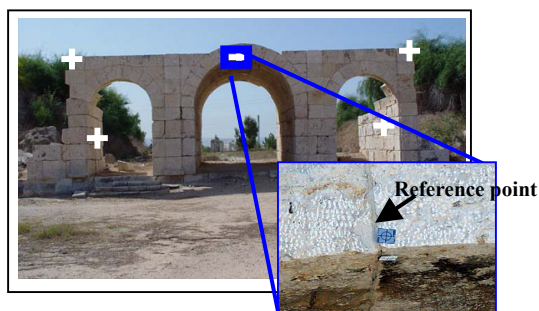


Figure 15. Distributed targets

### 4.4 Alignment

The obtained point cloud data were aligned as the following process.

- 1) The point cloud data is loaded, and the marks of reference points are displayed on the point cloud data as well as on the intensity image with the same angle.
- 2) Reference points are extracted automatically by using the reflectance image.
- 3) More than three reference points are selected manually.
- 4) The local coordinate values of reference points are converted to the world coordinate values, which are acquired by the total-station.

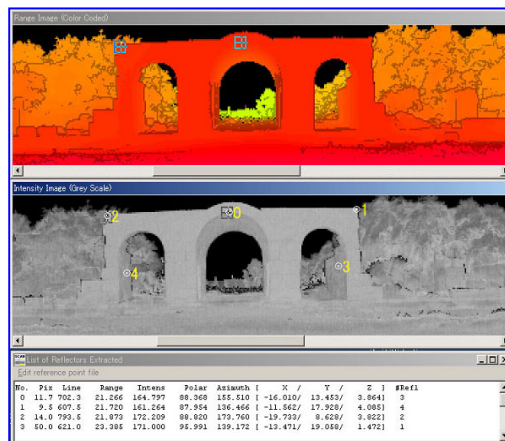


Figure 16. User interface for alignment (Top: Point cloud data, Middle: Reflectance image, Bottom: Data of targets)

When a model achieves small residuals at the tie-points, that is, the error value or standard deviation is less than 10cm, the model is selected and it is merged to the others in this stage.

The following figures show examples of aligned point cloud data. Those images can express shapes of features such as obelisks or stadiums in Hippodrome. The mean value of the error value is 0.043m.

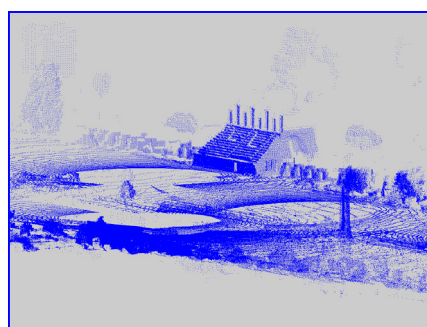
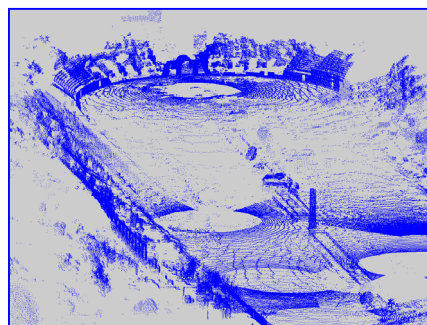


Figure 17. Aligned point cloud data of Hippodrome

## 5. ALIGNMENT OF CYRAX AND RIEGL DATA

After each alignment of Cyrax and Riegl data, both data were aligned with PolyWorks.

The aligned Riegl data ranged a wide area including the memorial gate and the stand of Hippodrome. The aligned Cyrax data of the memorial gate and that of the stand of Hippodrome were aligned to the Riegl data by means of finding out corresponding points in each data, using PolyWorks (Figure 18). Thus combined two different types of laser scanning data has become a base of archaeological 3D-GIS, which covers wide area of remains, while recording the details of important monuments.

The authors believe that the results obtained will play an important role in the archaeological surveys conducted hereafter as an archaeological 3D-GIS database where archaeologists can make access and add new findings and results on it easily. And it will improve drastically the management of archaeological information in Tyre.

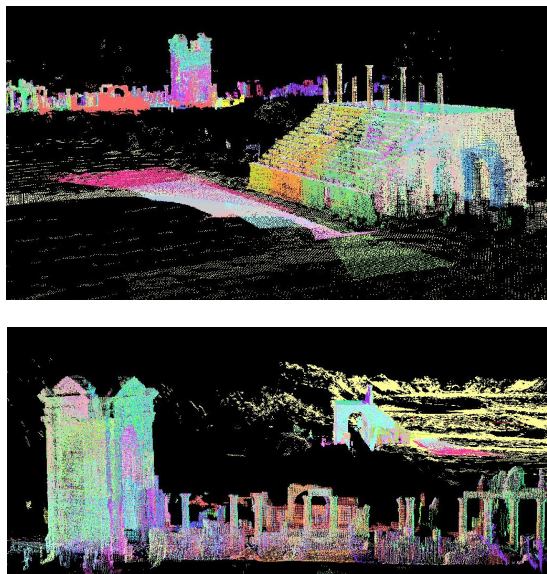


Figure 18. Aligned Cyrax and Riegl data

## 6. CONCLUSIONS

Since the laser scanning was done with the scanner placed on the ground, some portions of the objects, especially those at high positions could not scanned. For large scale objects, some ways of measurement from higher position than their heights, such as the use of scaffoldings or cranes for laser scanning as well as the use of digital stereo photography from radio-controlled helicopter should be introduced.

While the geometry of laser-scanned object can be automatically generated, texture mapping onto it still requires considerable manual work. The authors think it very necessary to develop a measurement system which can obtain 3D geometric data together with fine color image data, in the way that the texture can be automatically, or very easily mapped onto 3D geometry model of the object afterwards. The combination of laser scanning and digital photogrammetry also should be considered.

When the area of 3D measurement gets geographically wide, it becomes necessary to develop a 3D-GIS system where users can make access to 3D excavation database and add new results on it very easily. Providing linked 3D overview map and

individual site data, such system will improve drastically the management of archaeological information.

The authors are starting to make CG animation of the monuments in Tyre, using 3D data obtained in the survey, while we are writing this paper. We plan to finish it before the workshop and hope to show it at Ancona this summer.

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## Acknowledgements

The authors greatly thank to the General Directorate of Antiquities, Ministry of Culture, the Republic of Lebanon, especially to Mr. Assad Seif, who made our survey possible and gave us a great deal of support in Tyre.