Bayon Digital Archival Project

Katsushi IKEUCHI*, Kazuhide HASEGAWA*, Atsushi NAKAZAWA**,
Jun TAKAMATSU*, Takeshi OISHI* and Tomohito MASUDA*

**Institute of Industrial Science, University of Tokyo*
4-6-1 Komaba, Meguro, Tokyo, 153-8505, JAPAN
Email: {ki, k-hase, Oishi, j-taka, tom}@cvl.iis.u-tokyo.ac.jp

***Cybermedia Center, Osaka University*
1-32 Machikaneyama, Toyonaka, Osaka, 560-0043, JAPAN
Email: nakazawa@ime.cmc.osaka-u.ac.jp

Abstract. We have been digitizing the Bayon temple, which is located at the center of Angkor-Tom in the kingdom of Cambodia. We have been planning three times on-site measurement, and have thus far completed the second mission. In this paper, we will present an overview of this on-going "Bayon Digital Archival Project". This project has three main topics: global geometry, face library, and fine geometry. With Global geometry, we aim to digitize the entire Bayon temple, which is more than 100 m length on each side by 43 m height at the most. For digitizing this large architecture, a novel aerial sensing system called the Flying Laser Range Sensor (FLRS) has been introduced in the project. We have also been digitizing the calm and smiling faces carved in each tower, and we will construct a face library. Beautiful and interesting reliefs carved on double corridors have been archived as well in the topic of fine geometry.

1. Introduction

Currently, so many cultural heritage objects are deteriorating or being destroyed in the world. To avoid losing these heritage objects, a preservation work is an overriding issue for the human race. Furthering, computer vision technique, laser range sensing technology and personal computer performance have been improving considerably. Therefore, digital preservation is a practical and potential solution for preserving cultural heritage objects. We believe that digital preservation is one of the best ways to accomplish this preservation. The advantages of digital preservation are as follows:

1. Current conditions of heritage objects can be preserved permanently.
2. Preserved digital data is expected to serve as guidelines for restoration work.
3. Digital data can be used for computer simulation.
4. A virtual reconstruction for media contents is easily performed at reasonable, inexpensive cost.

We have been conducting a project to archive cultural heritage objects: the "Great Buddha Project" [1]. Several cultural heritage objects such as the Kamakura Great Buddha, the Nara Great Buddha and the Atchana Buddha have been archived thus far. Moreover, several sophisticated modeling techniques have been studied and developed during the project. We started the "Bayon Digital Archival Project" in 2003, using these developed techniques.

The Bayon temple, located at the center of Angkor-Tom in the kingdom of Cambodia, is remarkable architecture and a large scale site. Unfortunately, some part of the Bayon temple was destroyed during civil wars and Pol Pot's dictatorship. Preservation and restoration work of the Bayon temple had been begun by the Japanese government team for Safeguarding

Angkor (JSA) [2]. Our project is operated in cooperation with the JSA. The motivations of our project, the “Bayon Digital Archival Project” are:

1. Preserving this historically important cultural heritage object.
2. Extending our developed techniques for adapting large scale sites.
3. Developing a new sensor for reducing unobserved regions from conventional laser sensors.

This paper is organized as follows. In Section 2, we briefly describe our developed techniques: Modeling from Reality. In Section 3, we discuss a few additional details of the Bayon temple. Then, in Section 4, the details of our project “Bayon Digital Archival Project” are described, and modeled results are shown. In addition, a novel aerial range sensing system, the Flying Laser Range Sensor (FLRS) is introduced. Finally, this paper is summarized in Section 5.

2. Modeling from Reality

There are three important modeling techniques for generating realistic digital contents; geometric modeling, photometric modeling and environment modeling. In our laboratory, all of these three aspects have been studied and developed into sophisticated techniques during the “Great Buddha Project”. In the “Bayon Digital Archival Project”, we have used the geometric and photometric modeling techniques thus far, and we intend to apply the environment modeling technique as well.

2.1. Geometric Modeling

Geometric modeling enables us to obtain shape information of objects. Our technique consists of three steps: Data-acquisition, Alignment and Merging. In the data-acquisition step, we use a laser range sensor to measure a surface geometry. The laser range sensor provides us highly accurate range data but only a partial surface of objects. Thus, by considering the density of point data, complexity of surface geometry and circumference, several measurements are usually performed on a single object.

Each piece of range data obtained from a different viewpoint has its own coordinate system; therefore, the next alignment step becomes necessary. We use a simultaneous alignment method, developed in our laboratory [3]. A pair-wise alignment method accumulates large errors when used for large data sets. Our alignment method avoids the accumulation errors by estimating all range data simultaneously, and achieves high speed calculation by utilizing graphic hardware for estimation.

The last step is merging. After all range data have been aligned to a common coordinate system, those partially overlapped surfaces are converted into a single surface, called the consensus surface. We employed octrees to represent a volumetric implicit-surface representation with signed distance field [4]. In both the alignment and merging steps, a PC cluster system is used in order to reduce computational cost and memory consumption. Without this PC cluster system, large data sets obtained at the Bayon temple cannot be handled at all.

2.2. Photometric Modeling

Photometric modeling is also an important technique for preserving some kinds of cultural heritage with original painting at the time of construction. For such cultural heritages, we need to model photometric information as well as geometric information, and to estimate relationship between geometric and photometric information in order to perform texture mapping. The parameters of the relationship between them can be estimated easily with a well-known calibration method if the object to be digitized is relatively small in size. However, if the digitizing object is large scale, as in the case of the Bayon temple, using this method is quite difficult since calibration tools should be almost the same size as that of the object. To overcome this problem, we have developed a novel parameter estimation method that uses edge information of reflectance values in range data and color images photographed by a digital camera [5]. Reflectance value is a power ratio of outgoing and incoming laser spots and provided by the most type of laser range sensors. In our method, by comparing edges between reflectance and color, the parameter can be estimated without calibration tools. Texture-mapped models shown in this paper were performed by this calibration free method.

3. Bayon temple

The Bayon temple is located at the center of Angkor-Tom in the Kingdom of Cambodia and unites the outlook on the universe of ancient India and the tradition of Khmer. The temple was constructed around the end of the 12th century to give relief from the crisis in the Angkor era. It is well known for the appearance of, for example, 51 towers, more than 100 m length on each side by 43 m height at the most, 173 calm, smiling faces carved on towers, and double corridors carved in beautiful interesting reliefs. As time went by, the condition of the Bayon temple deteriorated due to civil wars, Pol Pot's dictatorship, and natural disasters; the condition of the architecture was in serious crisis. Preservation and restoration work at the temple had been begun in 1994 by the Japanese government team for Safeguarding Angkor (JSA). Fig.1 shows pictures of the Bayon temple.

Fig.1 Pictures of Bayon temple.
(Top picture: entire Bayon temple; Bottom picture: Faces carved on towers)

4. Bayon Digital Archival Project

In cooperation with the JSA, we started the "Bayon Digital Archival Project" in 2003, using the techniques developed in the "Great Buddha Project". The three main topics of our project are:

1. Global Geometry: Entire Bayon temple
2. Face Library: Faces carved on towers
3. Fine Geometry: Reliefs on corridors

By using global geometry, we aim to digitize the large and complicated structure of the Bayon temple. For digitizing this large architecture, a novel aerial sensing system called FLRS (Flying Laser Range Sensor) had been introduced and used in fieldwork measurement. We have also been digitizing the calm, smiling faces carved in each tower and will construct a face library. Beautiful and interesting reliefs carved on double corridors have been archived as well in the topic of fine geometry.

We have been planning three times on-site measurement, and we have completed the first and second missions thus far.

First mission: 16^{th} Feb. ~ 9^{th} Mar. 2003
Second mission: 14^{th} ~ 31^{st} Dec. 2003
Third mission: Dec. 2004 (TBD)

In each mission, about 15 people (laboratory's staffs and students) stayed in Siem Reap city for measurement. We employed bellow sensors.

First mission: Cyrax 2500 2 sets, Vivid 900 & 910, Z+F Scene Modeler (system failed), FLRS (system failed)
Second mission: Cyrax 2500 2 sets (one system failed), Vivid 910 2sets, Z+F Imager 5003, FLRS

A Cyrax 2500 is a long range type laser range sensor and takes about 10 minutes for a single measurement [6]. A Vivid is a short range type range sensor based on a cross-section method and takes about 3 seconds [7]. Z+F sensors is an omni-directional laser range sensor [8]. Due to high ambient temperature at the site and vibration of ground transportation in Cambodia, the sensor system is failure-prone. Even though we prepared well, we could never use every sensor, and always someone's health was upset.

4.1. Archiving Entire Bayon Temple

As we mentioned, the Bayon temple consists of 51 towers with double corridors. Fig.1 shows the complexity and large scale size of this object. There are also many pillars in the corridors and notches between corridors and terraces. These make many occluded regions from laser range sensors; therefore, we usually need to perform measurements from several viewpoints. In addition, high positions such as the roofs of corridors and the tops of towers cannot be observed by laser range sensors placed on the ground. Therefore, we introduced the FLRS and actually used it in fieldwork measurement.

Sensing from the Ground

In the first and second missions, we used Cyrax sensors and a Z+F Imager for archiving entire Bayon temple. The numbers of range images taken are:

First mission: 228 range images with Cyrax
Second mission: 168 range images with Cyrax
153 range images with Z+F Imager

Fig.2 shows the measurement results obtained in the first mission, and Fig.3 shows the results obtained in both missions. In the first mission, we chiefly measured the north towers, and Fig.4 shows the texture-mapped model. Texture images used in the model were photographed with a digital camera, and texture mapping was performed by means of our calibration free method.

As one can see, by combining both mission results, Fig.3 is complemented from the fist mission, shown in Fig.2, but there are still racked regions. Therefore, we are planning a third mission for complementing the remaining regions. In Fig.4, Color adjustment between texture images has not yet been performed. We intend to use our environment modeling technique after completing the third mission.

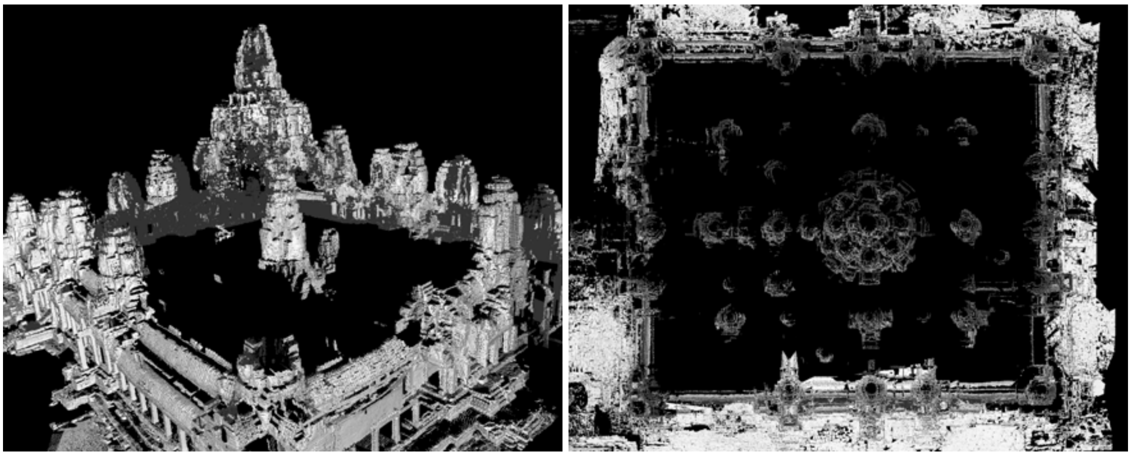

Fig.2 Measurement results of entire Bayon temple in first mission.
(Right picture: top view)

Fig.3 Measurement results of entire Bayon temple obtained thus far.
(Views from the same position of Fig.2)

Fig.4 Texture-mapped model of the north towers

Aerial Sensing with FLRS

In a measurement operation with laser range sensors placed on the ground, when an object becomes larger or higher, the occluded regions increase more and more. We generally put up scaffolding in such cases and measure from the top. This scaffolding technique is a practical solution but time and cost consuming. Considering the Bayon temple, we need to put up a great deal of scaffolding in order to cover towers and a wide area. To overcome these problems, we have been developing the FLRS that is designed to be suspended beneath a balloon platform [9]. This sensor achieves high speed measurement but still suffers from movement of the sensor itself. We have also been studying methods for correcting distortion in obtained data; this distortion is caused by sensor movement. So far, four methods have been developed, and we intend to compare and fusion appropriate methods. Fig.5 shows a close-up of FLRS and the measurement scene carried out in the Bayon temple in the second mission. Table 1 contains the specifications of the FLRS.

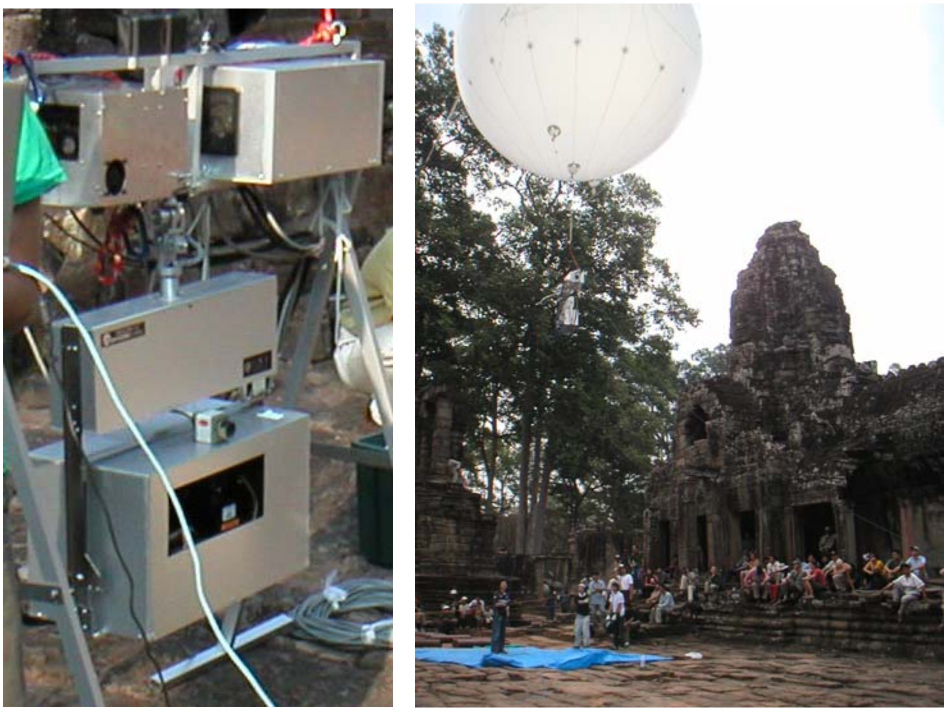

Fig.5 FLRS (Flying Laser Range Sensor)
(Left picture: Close-up; Right picture: Measurement scene)

Table 1 Specifications of FLRS

Scan resolution	3600 * 160 pixels
Range image resolution	1800 * 160 pixels
Measurement speed	1 sec / range image
Vertical field angle	30 degree
Horizontal field angle	45 degree
Weight (Laser scanner)	21.2 Kg
Weight (Controller and PC)	16 Kg

We usually obtain measurement results such as Fig.6 by using ground sensors only. Viewing from a lower angle, we can confirm that enough dense data was obtained. Viewing from an upper angle, however, shows that there are lacked regions that were occluded from the ground sensors. On the other hand, in Fig.7, the lacked regions had been complemented by aligning 4 pieces of range data obtained by the FLRS and data in Fig.6. Clearly, aerial sensing is a practical solution for archiving cultural heritage objects and the FLRS can provide precise results.

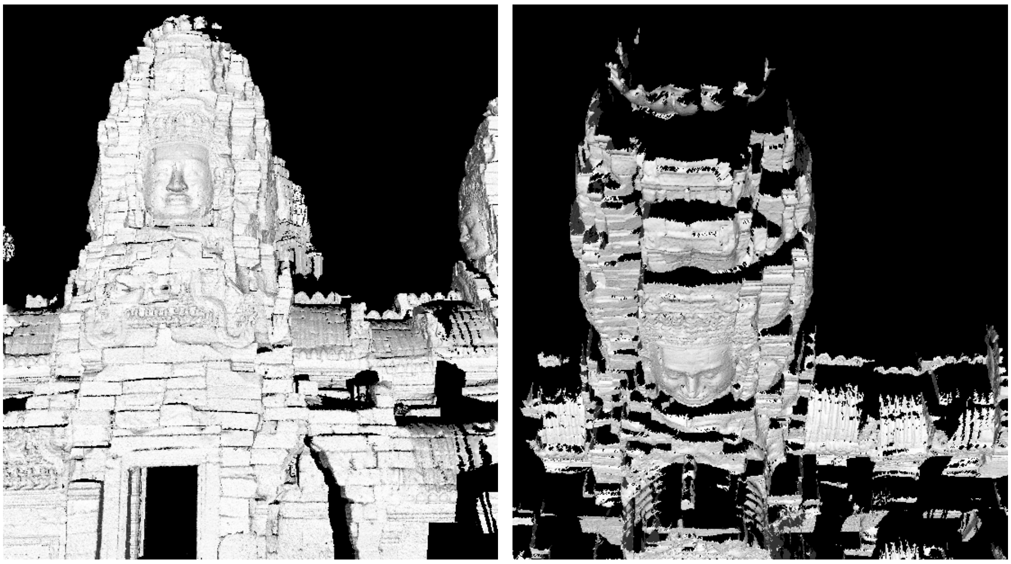

Fig.6 Measurement result obtained by ground sensor Cyrax 2500
(Left image: Displayed from lower angle; Right image: Displayed from upper angle)

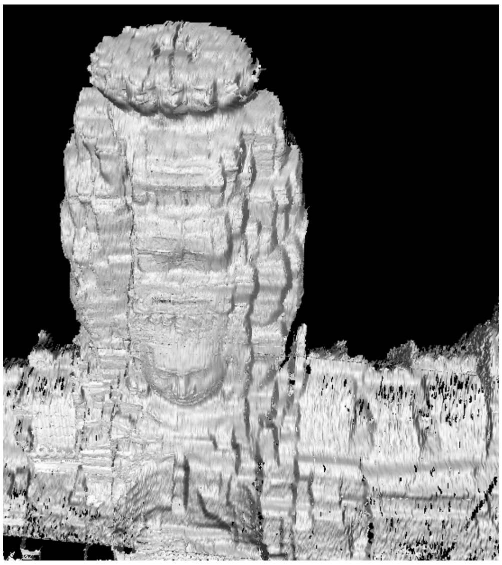

Fig.7 Aligned result with 4 pieces of range data obtained by FLRS and Fig.6

4.2. Archiving Faces on Towers

The number of faces carved on towers is estimated to be 173. It is difficult to estimate the exact number due to destruction or collapse. These faces were classified into three groups: Dava, Davatar and Asherah, according to the results of the JSA research [10]. Our goal is to archive all the faces and to then construct a face library. Thus far, we have selected typical faces carved on towers No. 18, 19, 20, 30, 33, 34, 35, 50, 51 and then measured them. Cyrax 2500 was mainly used for archiving faces, and we measured from 4 to10 times per face. Fig.8 shows the archived models of typical faces and Fig.9 shows texture-mapped models. Texture images were provided by the JSA and photographed by BAKU SAITO.

Fig.8 Archived models of typical faces
(Left image: Dava carved on tower No.51, south side;
Center image: Davatar carved on tower No.50, east side;
Right image: Asherah carved on tower No.35, north side)

Fig.9 Texture-mapped models of Fig.8

4.3. Archiving Reliefs Carved on Corridor

The Bayon temple contains double corridors. Both inside and outside corridors are carved in beautiful, interesting reliefs. Thus far, we measured reliefs carved in the north inside corridor in the first mission, and the south outside corridor in the second mission. We used Vivid sensors for measuring shapes, and the digital camera attached to the top of the Vivid for obtaining color images. Fig.10 shows archived relief model carved on the north inside corridor; 151 range images were aligned and merged with our geometric modeling techniques. Fig.11 is one portion of the same corridor and 11 color images were texture-mapped.

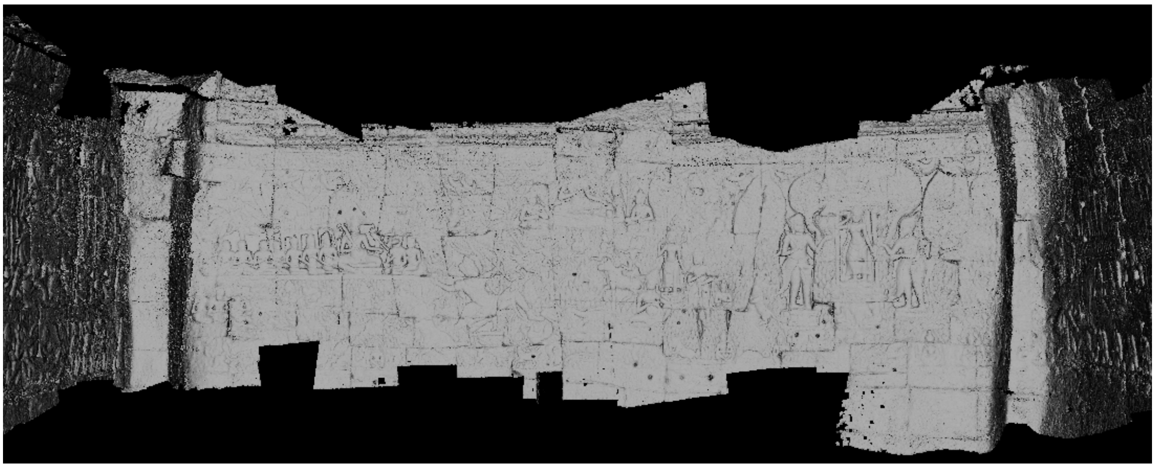

Fig.10 Archived model of north inside corridor

Fig.11 Texture-mapped model; one portion of Fig.10

5. Conclusion and Future Work

This paper has presented an overview of the "Bayon Digital Archival Project" that is now in progress. We have been planning three missions of fieldwork measuring, and have thus far completed the second mission. In this paper, some archived models are shown: the entire Bayon temple, some of the faces carved on towers and reliefs carved in corridors. These models were generated by means of our techniques developed in the "Great Buddha Project." We also introduced a novel laser range sensor, the Flying Laser Range Sensor (FLRS) that can measure from high positions without any scaffolding.

For future work, during the third mission, we are planning to complement remaining regions in the model of the entire Bayon temple and measure as many faces carved on towers as possible. After completing the third mission, we intend to apply our environmental modeling technique to the model of entire temple and construct a face library as well. A survey drawing of the entire Bayon temple was created about a half century ago by a French team [11]. We are also considering a comparison between the survey drawing and our archived model of the entire temple.

Acknowledgement

This study was supported, in part, by Japan Science and Technology cooperation (JST) under the CREST program. Measurement operation in the Bayon temple was in cooperation with the Japanese government team for Safeguarding Angkor (JSA).

References

[1] D. Miyazaki, T. Oishi, T. Nishikawa, R. Sagawa, K. Nishino, T. Tomomatsu, Y. Takase, K. Ikeuchi, "The Great Buddha Project: Modeling Cultural Heritage through Observation", Proc. of the 6th International Conference on Virtual Systems and Multimedia, October 2000.

[2] http://www.angkor-jsa.org/

[3] T. Oishi, R. Sagawa, A. Nakazawa, R. Kurazume, K. Ikeuchi, "Parallel Alignment of a Large Number of Range Images", Proc. of the 4th International Conference on 3D Digital Imaging and Modeling, January 2003.

[4] R. Sagawa, K. Nishino, M. D. Wheeler, K. Ikeuchi, "Processing of Range Data Merging", Proc. of IEEE/RSJ International Conference on Intelligent Robots and Systems, October 2001.

[5] R. Kurazume, K. Nishino, Z. Zhang, and K. Ikeuchi, "Simultaneous 2D images and 3D geometric model registration for texture mapping utilizing reflectance attribute", Proc. of 5th Asian Conference on Computer Vision, January 2002.

[6] http://www.cyra.com/

[7] http://konicaminolta.jp/

[8] http://www.zofre.de/

[9] Y. Hirota, T. Masuda, R. Kurazume, K. Ogawara, K. Hasegawa and K. Ikeuchi, "Designing Laser Range Finder Suspended Under A Balloon", Proc. of Asian Conference on Computer Vision 2004, January 2004

[10] JSA, "Annual Report on the Technical Survey of Angkor Monument", 1998

[11] "LE BAYON; HISTOIRE ARCHITECTURALE DU TEMPLE", 1967