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Development of a Photo-Realistic Digital Photogrammetry System

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Abstract

This paper deals with data capturing system for digital archive of cultural monuments. Although photo-realistic 3-D digital model is attracting keen interest, data capturing for large objects is not a easy task. An integrated system, composed of real-time kinematic GPS, non-prism laser range finder and two digital cameras, has been developed to achieve 10cm absolute accuracy. The system was tested at Byon Temple in the Angkor Monument, Cambodia. As the result of field test, accuracy for center of picture frame was less than 10cm, but greater error was detected in peripheral of image. The major reasons of poor accuracy was due to uneven distortion of digital camera lens, insufficient resolution of digital camera and mechanical structure of camera supporting bar. Workload analysis proved that this system may reduce work time at site, but still requires indoor works for data processing.

1. Introduction

Digital archive of cultural monuments has been attracting keen interests from different disciplines. Using virtual reality (VR) technology, people can experience virtual walk through in monuments at web site, and they can see how the original construction of ruin was, how they build the ruin, or how it was weathered over time. This would be fun to people, but also there are important rolls of digital archives in historical preservation and restoration projects.

Digital archive can be used in various stages of a project, such as in master planning, project scheduling, logistics and work management. For example, In restoration site, we may have different opinion over surface finishing of new materials. Someone may insist that new stones should look alike old ones, so that they should be artificially weathered and tinted, while another may insists that they should be remained in new appearance so that they can be easily distinguished from originals. In such case, simulated view of restored

monuments may be useful in drawing conclusion in discussion.
Advantage of digital archive is not only in VR and simulation. Standardized 3-D data can be exported to other systems, such as CAD, GIS and structural analysis.
Among several types of data structure in 3-D spatial data(Kubo, 1996), photo-realistic 3-D data, which is equal to full textured (or mapped) data model over surface or solid models, is discussed in this paper.
Although photo-realistic 3-D model has great potentials, difficulties for capturing primary data and building model has been the largest obstacle for utilization.
This paper deals with new data capturing system which is all digitally processed, and requires less time and experience than conventional close-range photo-grammetric systems.

2. Designing a New Digital Data Capture System

2-1 Byon Temple, Angkor Monument

As the primary data acquisition, close-range photogrammetry has been the most commonly used method, however, it has limitations both in setting and also in time and cost. The largest obstacle in employing conventional photo-grammetric method is setting control points on objects, in particular on high towers and walls. Japanese Government Team for Safeguarding Angkor (JSA) has been working in preparing master plan of Byon Temple in the Angkor Monuments, Cambodia. This temple is very complex massive stone structure sizing 140 by 160 meters, with two levels of terraces with surrounding corridors, a tall central tower and a number of small towers with Buddha relieves. It is considered to be very difficult to employ conventional close range photogrammetric methods, so that new system is designed.

Fig. 1 Complex structure of the Byon Temple, Angkor Monument, Cambodia

2-2 Requirement for the innovative system

There are three major requirements for the innovative data capturing system.
1) no controlling point on object
It is difficult to set up markers on tall tower. Beside this, as the main building is surrounded by tall corridors, there is very small space for photographing, so that numbers of stereo pairs may be very large.
2) digital processing
All data is digitally captured, no need for wet developing films and enlargement. All works can be done by a lap-top, so that large equipment such as stereo plotter is not required. Result can be checked at field, so that errors can be fixed at the site.
3) Easy and fast operation
As the climate of the site is very hot and wet (in rainy seasons) or dusty (in dry seasons), working conditions is not good for operators. Fast data capture is required. Easy operation is another requirement in archeological site. There may not be photogrammetric specialists available at field.
4) Capturing texture simultaneously
Shapes and texture must be captured at the same time. As most ruins are decayed and weathered, many corners of ruin walls are not in right angle, edges of

stones are curved, and surface of stones are not flat. Conventional line drawing may drop some of features, so that ortho-photograph is suitable for recording those objects. In this system, objects are measured by digital-photogrammetry and original photography with texture and color can be easily draped on 3D shape data.

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3. Components and Basic Principle

3-1 Basic Components

The system is composed of three major modules, a position capturing module, photogrammetric module, and control software module. The position capturing module is composed of Real-time kinematic GPS system(RTK-GPS) and a non-prism laser range finder (LRF). The photogrammetric module consists of two digital cameras and three laser pointers. All components are mounted on an aluminum 2 meter bar. Three laser pointer is also mounted on the bar which point center of left camera, right camera, and measuring point of LRF. In addition, a reference scale bar is placed parallel to base line, between the system and object. Three markers (with plastic seal prism) are located on reference bar, all one meter apart. This bar is used for calibrating systems and giving scale and focal distance parameter.

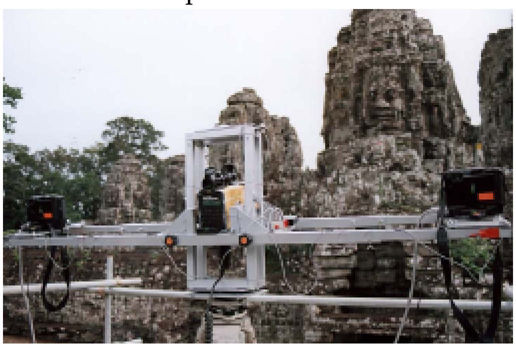


Fig. 2 System

GPS, LRF and digital cameras are controlled from a lap top PC. GPS and LRF are connected via serial port, where digital cameras are connected by SCSI interface.

Fig. 3 Reference scale bar

3-2 Basic principles

The primary location of the system is positioned by RTK-GPS within 2cm accuracy. Position of GPS is converted to UTM to match with LRF.
A pair of two digital cameras capture a stereo pair of digital photography. As there is no control points, or given position on object, two visible red laser (635nm, 5mw) point centers of camera frames, and another laser point the target point for the LRF, which is in the middle of camera frame centers.
LRF provides two types of basic parameters; distance between the object and the system and position parameters of systems (tilt and azimuth). Combining these data, XYZ positions on object can be measured by photo-grammetric process. Adding extra controlling points using LRF provide better accuracy.

3-3 RTK-GPS

The primary position of the system is given by RTK-GPS. The base station for RTK-GPS was placed near Prasat Suor Prat, on a bench mark previously measured by static GPS measurement. A Novatel RT-2 engines and a Aero

Antenna Technology AT2775 antenna is used with a Yaesu YRM-211T packet modem and 5W amplifier for transmission. RTCA, Novatel in-house protocol for RTK correction was used.

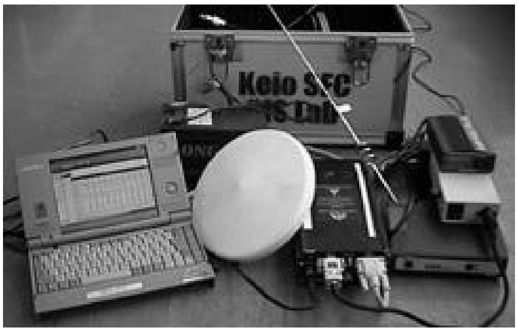
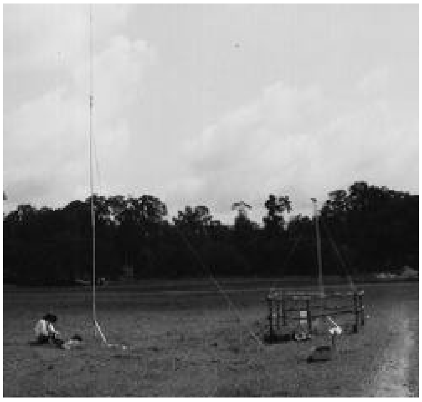


Fig. 4 GPS components

Industrial standard RTCM was not used because size of packet is too large in RTCM. GPS antenna and a rod antenna for data link is high mounted for better receiving and transmission.
For the rover station, same engine and modem is used with a pre-amplifier. Antenna is mounted on frame.

Fig. 5 GPS base Station



3-4 Non-prism LRF

Laser Technology Criterion 400 was mounted on the center of camera mount. This LRF has 3cm accuracy distance, which is relatively poor for measurement. Azimuth is measured by magnetic compass, which we found problem with remaining magnetism of laterite stones.

Fig.6 Non-prism LRF

3.5 Digital camera

Two Fuji-Film DS300 digital camera were mounted on a camera bar. This digital camera has 1280 by 1024 pixels, which is assumed insufficient resolution for photogrammetric purposes. In spite of poor resolution, shutter, zoom factor and image transfer can be controlled from PC. Motor drive zoom control is inaccurate so that focal length may be unstable which would increase errors. Also lens has relatively big distortion. Recent inexpensive digital camera with 3 mega pixels may provide better results.

Fig.7 Digital Camera

3-6 Software

Most software is in-house written in Visual Basic Language, however, commercial package is used for ortho-photo production.

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4. Data capture

4-1 Shape capturing

Shape of object is captured by pointing a point on object in left image by mouse. Corresponding point in right image is automatically detected. Sub-pixel matching was not applied in the program used. A part of the South Library was plotted as Fig.9.

Fig.8 South Library of Byon
(left image of a stereo pair)

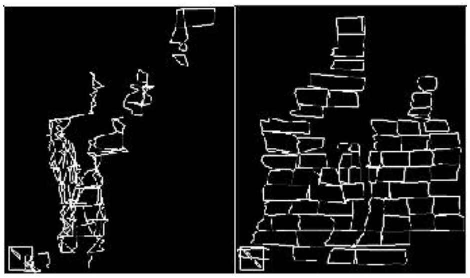

Fig. 9 Wire frame data generated from

4-2 Surface model and ortho-photographs

From stereo pair, surface model and ortho-photographs are generated. Figure 10 shows a stereo pair of Buddha relief on the north facade of tower on the North Entrance, Byon Temple. Figure 11 shows shaded surface model produced from the stereo pair shown in figure 10 and Figure 12 shows ortho-photography. Commercial software *Keisoku-meijin* was used.

Fig. 10 Stereo pair of Buddha relief

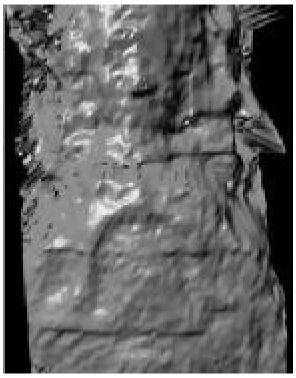

Fig.11 Shaded Surface model

Fig.12 Orthophotograph

5. Textured Model

5-1 Textured mapping

Texture can be mapped on 3-D models using various commercial rendering software. Texture mapped data can be viewed using viewer software such as VRML viewer. Figures 13 and 14 show textured image of Bakong Temple in Roluos Monuments near Angkor.

Fig. 13 Texture image of Bakong

Fig. 14 Textured image of a gate of Bakong

6. System Evaluation

6-1 Accuracy test of measurement

Accuracy test was done at the north wall of the South Library. Prism seals were placed on walls and measured positions by a SOKKIA total station with accuracy of less than 1 cm. By comparing coordinates calculated by this system and measured positions, accuracy of the system can be tested.

As the result, there was a 5.5 cm absolute error (from global coordinates) in horizontal direction of image (X), 3.1 cm in vertical direction(Z), and 31.6cm in depth direction (Y) in central part of a image. But in the peripheral of the same image, error is fur large as 27.6cm, 26cm and 99.2cm respectably. The error is less than original goal (10cm) in X and Z directions in central part of image, but greater than in Y direction. In peripheral of image, there remains large error.

6-2 Error factors

Error may be caused by the following factors;

1)errors caused by cameras
   errors due to unfixed focal distance
   lens distortion
   insufficient resolution
2)errors caused by unreliable parameters
   errors due to projection angle
   errors due to baseline length
3)errors due to hardware unreliability
   bend and distortion of camera mount
4)errors due to software
   stereo matching accuracy

Some of those error factors can be adjusted by improving software, such as introduction of better lens distortion calibration and sub-pixel stereo matching. Some other factors relates to performance and accuracy of hardware components. It can be improved by changing camera, and replacing sensors to precise ones.
Rests of error factors are mostly related to assemble accuracy of camera bars and mount.

6-3 Cost of the system

Hardware costs for the system is approximately 6 million yen (50,000 USD at current exchange rate), not including software costs.

6-4 Performance evaluation

Labor at site and laboratory is another important factor for evaluation. In this system, work time under severe climatic condition is minimized. Required time for each operations are as follows;

GPS base station setting	10min.
GPS disassembly	5 min.
System assembly	10min.
System disassembly	3 min.
Moving to next capturing position	10 min.
Calibration	15min.
Data capture	3 min.
Data process and mapping	3 hrs.

A standard model for evaluation is assumed that 4 capturing positions per day and 5 stereo pairs at one position.

Work time for setting/disassembly
In this model, setting and disassembly of systems requires 35 minutes in total.

Initial setting/disassembly for one day	
GPS setting	10 min.
System assembly	10 min.
GPS disassembly	5 min.
System disassembly	10 min.
Total	**35 min.**

Work time for setting at each position
For all 4 sites, calibration is required.

Initial setting for each location	
System calibration	15 min.
Total	**15 min.**

Work time for capture
Most time required for data capture is directing the system to desired angle, and uploading images to PC.

Operation time at each location	
Data Capture x 5 frames	15 min.
Total	**15 min.**

For each position, 30 minutes are required to capture 5 stereo pairs. For 4 positions, 2 hours are required.

Total work time for a day (4positions, 20 stereo pairs):

Initial setting/disassembly	35min.
Calibration	60min.
Data Capture	60min.
Time for moving	30min.
Total	**185min**

Lab operation:

Data processing and mapping	60hrs.
Total	**60hrs.**

This work load analysis shows that work time at site is considered far shorter than conventional photogrammetric methods because of eliminating bench mark setting at each sites. However, data processing requires much more time and also numerous operators. This analysis does not includes time for data checking at site. Minimum checking of data is by finding inconsistency of positions derived from different stereo pairs. Also plotting some points may be helpful in finding errors. This operation may requires 10 additional minutes for each stereo pair, so that total work time may be increased to 385 minutes.

7. Conclusion

Four major aims initially set for development of this system is as follows;

(1) No benchmark or control points on object, and maintain permisible accuracy
(2) A system with full digital operation
(3) Easier operation and less working time at site than conventional photogrammetric systems
(4) Full texture capture capability

Most of initial goals are realized but with accuracy. As described previously in this paper, the largest error factors are in camera systems and accuracy of sensors. For non-benchmark systems, accuracy of

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total system depends on accuracy on each sensing devices. As general theory, device with higher accuracy costs far expensive than ones with standard accuracy. To avoid this paradox, in this system, as a basic idea, higher redundancy concept in parameters, which means a parameter can be measured by different types of sensors and checked, is introduced.

In performance test, we found that still accuracy, Y direction in particular, is not as good as we originally expected. As most error factors are already known, so that the system will be improved to achieve intended accuracy.

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