Available online at www.sciencedirect.com
ScienceDirect
Advances in Engineering Software 38 (2007) 501–512
ADVANCES IN ENGINEERING SOFTWARE
www.elsevier.com/locate/advengsoft

3D scan for the digital preservation of a historical temple in Taiwan

Naai-Jung Shih *, Huey-Jiun Wang, Chen-Yan Lin, Chai-Yuan Liau

National Taiwan University of Science and Technology, 43, Section 4, Keelung Road, Taipei 106, Taiwan, ROC

Received 13 September 2005; received in revised form 1 September 2006; accepted 4 September 2006
Available online 23 October 2006

Abstract

This study presents the efforts in archiving Chinese architecture using a long-range 3D laser scanner. A historical architecture, the main hall of the Pao-An Temple, was preserved in a digital format with the architectural shapes retrieved more accurate than traditional manual measurements did. The difficulties in measuring as-built free forms and curves up to the size of a building were encountered and solved to enable the display of the hidden inter-relationship between outdoor and indoor profiles through sections. This research identified the most error-prone measurements done by traditional approach by comparing original drawings with the final models which registered 1958 scans and sub-scans. To represent the special characteristics of as-built 3D temple form, the study includes the application of metadata in architecture, the information management of digital data, and the Internet display of large 3D data sets.

Keywords: 3D laser scanner; Historical preservation

1. Historical background: Pao-An Temple

The Pao-An Temple has gone through two major renovations. As survey, design, drawing production, and construction processes were conducted, all the construction efforts were recorded in two dimensions. The constructions and the renovations over 170 years evidenced long-term efforts in preserving this religious asset. Nevertheless, construction site monitoring is a continuous process that data should be recorded and monitored for immediate or post-construction analysis [1,2,11]. Records made by 2D drawings have limitations in describing the allocation of geometries in 3D space precisely, based on discrete manual measurements. Each renovation should be recorded afterward to update as-built 3D database for future renovation or for the monitoring of possible wood frame sags in 170 years.

Active surface measuring techniques have been used to automatically reconstruct 3D models by joining polygon meshes since 1994 [15]. The techniques enable highly accurate measuring of 3D surfaces. The developments in long-range finders have enabled the laser scan of large objects [3]. One distinct example conducted by the Stanford Computer Graphics Laboratory was the Digital Michelangelo Project, in which the statue of David was scanned [5,14].

To make the best of as-built data for architectural use, this study has enlarged the scope to a temple and increased the complexity in registering the concave geometries of exteriors and interiors together.

2. Research purpose

The purpose of this study is to create as-built 3D computer model of a Chinese temple for digital preservation need. The model has to combine temple exteriors and interiors, in order to show the double-eave mountain-styled roof structure on both sides. The computer models of temple and its components have to be browsed on Internet up to the size of 200,000 points. The database also has to meet the specification of metadata. The preservation presents a reversed model construction process to integrate fragmental representation of temple parts used to be retrieved individually.

* Corresponding author. Tel.: +886 2 27376718; fax: +886 2 27376721.
E-mail address: shihnj@mail.ntust.edu.tw (N.-J. Shih).

0965-9978/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.advengsoft.2006.09.014

This study begins by presenting the historical background of Pao-An Temple, the characteristics of scan subjects, and why and how the scan technology and the system are applied. In order to present the 3D scan process, this paper is organized under the following order:

1. Historical background: Pao-An Temple.
2. Research purpose.
3. Scan subjects.
4. Scan system.
5. Scan and registration.
6. Metadata and 3D data display.
   Center database and naming system.
7. 3D scan data verification.
8. Integrate fragmental representation through a reversed model construction process.
9. Comparing to photogrammetry method.
10. Limitations.
11. Conclusion.

3. Scan subjects

The Emperor Pao-Shen, named "Wu Tao", is the focus of worship at Pao-An Temple. He was renowned for medical skill and saving numerous lives. Initially, a small and crude temple made of wood was constructed between AD 1755 and 1760. The current structure was constructed between AD 1805 and 1830 [9] (see Fig. 1). The beauty of the religion-, architecture-, and art-related creations has made the Pao-An Temple a classic example in Taiwan. The Temple faces south with the layout similar to a loop made by three main halls (the entrance hall, the main hall, and the back hall) and two side rooms on east and west. The main hall, with double-eave mountain-styled roofs, contains four dragon pillars in front, as important relics from the initial founding stage of the Temple.

3D range images have been used to represent objects in various sizes from a small vessel to a whole archeology site. For those subjects small enough to be scanned in a well-controlled indoor environment, subjects can be oriented to eliminate blind spots and to measure Bidirectional Reflectance Distribution Function (BRDF) from different angles [8]. At an open site, range images often are incomplete for obstructions (self- or from other objects) or lack of bird-view scans. This is particular true when the double-eave mountain-styled roofs separate the temple into top and body. The open spaces around body were very narrow for wide angle scans. The spaces also restricted the accessible reference views for combining both interior and exterior scans at ground level. Although recent development of 3D scanner supports 360° field-of-view, the scanner still has to move around the temple to complete exterior scans segment by segment.

This was the first project in Taiwan to use a 3D scanner to record the main hall of a temple inside out. Pao-An Temple, which was classified as a level-two historical asset, has been surveyed by many researchers to create plans and elevations before and after recent renovation. Old studies were conducted by manual measurement using traditional instruments. Scaffolds were used intensively in order to reach places higher than human eye level. The temple was studied because a number of original drawings could be found to confirm or to compare with scan findings along the recording process, although drawings from previous studies were mainly 2D records.

In addition to the tremendous historical background, the Pao-An Temple was also selected because its surrounding buildings and back hall which are higher than the main hall made the unobstructed scans of roofs possible. However, the spaces around the main hall were barely enough to scan the area under the eaves: the main hall was surrounded by open corridors and eastern/western rooms that connect from the entrance hall to the back. A strategy was developed to combine a ground scan scheme for the body and lower eave with a bird's eye scan scheme for the roof (or top eave) from the neighborhood. The two schemes created the exterior appearance, which was later registered with interior scans to complete the entire configuration of the temple.

Fig. 1. The main hall exteriors and interiors, Pao-An Temple.