The Great Buddha Project: Modelling Cultural Heritage through Observation

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Abstract. This paper presents an overview of our efforts in modeling cultural heritage through observation. These efforts span three aspects: how to create geometric models of cultural heritage; how to create photometric models of cultural heritage; and how to integrate such virtual heritages with real scenes. For geometric model creation, we have developed a two-step method: simultaneous alignment and volumetric view merging. For photometric model creation, we have developed the eigen-texture rendering methods, which automatically create photorealistic models by observing the real objects. For the integration of virtual objects with real scenes, we have developed a method that renders virtual objects based on real illumination distribution. We have applied these component techniques to constructing a multimedia model of the Great Buddha of Kamakura, and demonstrated their effectiveness.

1. Introduction

One of the most important research issues in virtual reality is how to obtain models for virtual reality. Currently such models are manually created by a human programmer. This manual method requires long developing time and resulting virtual reality systems are expensive. In order to overcome this problem, we have been developing techniques to create virtual reality models through observation of real objects; we refer to these techniques as modeling-from-reality. As shown in Figure 1, the modeling-from-reality spans three aspects: how to create geometric models of virtual objects; how to create photometric models of virtual objects; and how to integrate such virtual objects with real scenes.

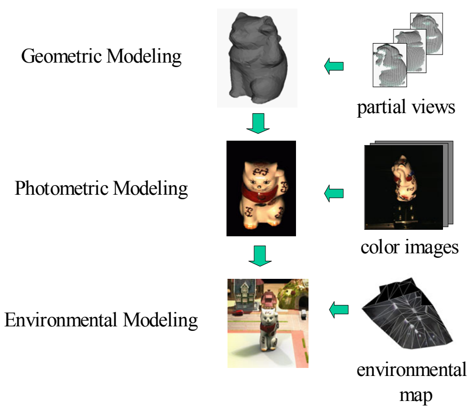

Figure 1 Three Components in modeling-from-reality

In this paper, we first overview the modeling-from-reality techniques in Chapter 2. Then, in Chapter 3, we explain how these component techniques were applied to model the Great Buddha of Kamakura, what kind of unforeseen difficulties are encountered, and how we solve them. Chapter 4 contains a summary of the paper.

2. Modeling from Reality

2.1 Geometric modeling

Several computer vision techniques, such as traditional shape-from-X and binocular stereo, or modern range sensors, provide cloud of point information. The cloud of point information certainly carries three-dimensional information pertaining to observed objects. However, there is no structural information among those points. Namely, there is no information to represent adjacency among the points. The first step of geometric modeling is to convert this cloud of points with a surface representation such as a mesh model as shown in Figure 2.

Since each observation provides only partial information, we have to connect these partial mesh representations into a whole geometric mesh representation. Thus, the second step in geometric modeling is to align these meshes so that the corresponding parts overlap one another. The third geometric modeling step is to merge these aligned data by weighing the reliability of each data point. For this view merging, we have developed a stochastic volumetric merging method.

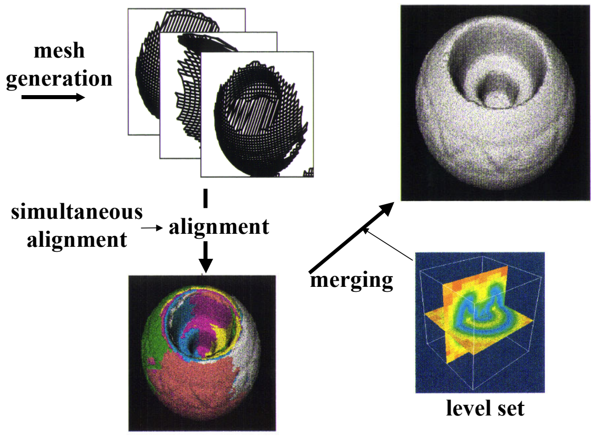

Figure 2 A three step method

2.2 Photometric Modeling

Currently, most VR (virtual reality) systems utilize image-based rendering [2,5,10]. The image-based rendering samples a set of color images of a real object and stores them on the disk of a computer. A new image is then synthesized either by selecting an appropriate image from the stored set or by interpolating multiple images. Apple's QuickTime VR is one of the earlier successful image-based rendering methods. Image-based rendering does not assume any reflectance characteristics of objects nor does it require any detailed analysis of the reflectance characteristics of the objects; rather, the method need only to take images of an object. On the other hand, image-based methods have critical disadvantages on application to mixed reality. Few image-based rendering methods employ accurate 3D models of real objects. Thus, it is difficult to make cast shadows under real illuminations corresponding to the real background-image.

We propose a new rendering method, which we refer to as the eigen-texture rendering method [12,13]. First, the eigen-texture rendering method creates a 3D model of an object from a sequence of range images. Second, the method aligns and pastes color images of the object onto the 3D surface of the object model. Third, the method compresses those images in the coordinate system defined on the 3D-model surface. This compression is accomplished using the eigenspace method. The synthesis process is achieved using the inverse transformation of the eigenspace method. Cast shadows are generated using the 3D model. A virtual image under a complicated illumination condition is generated by summation of component virtual images sampled under single illuminations thanks to the linearity of image brightness.

2.3 Environmental Modeling

Virtual objects are usually displayed with background by superimposing them onto a real/virtual background. For superimposing virtual objects onto an appropriate background [1,20], geometric and photometric aspects have to be taken into account; for environmental modeling, the virtual object has to be located at a desired location in the real scene, and the object must appear at the correct location in the image. At the same time, shading of the virtual object has to match that of other objects in the scene, and the virtual object must cast a correct shadow, i.e., a shadow whose characteristics are consistent with those of the shadows in the real scene.

3. Modeling the Great Buddha of Kamakura

By using the component techniques developed in the modeling-from-reality project, we have begun to obtain virtual models of historic heritage in Japan. We Japanese occupy a unique position in this respect. Most Japanese cultural heritages are made of wood and paper; thus, at any moment, they could be lost due to fire or water damage. It is important to create digitized representations of these cultural assets in order to preserve them for posterity.

As the starting point of the project, we obtain the geometric information of the Great Buddha of Kamakura. This Buddha was built in the thirteen century originally of wood, then of bronze. As a matter of fact, Japanese built a hall of the Great Buddha. It was destroyed three times by tidal waves. Figure 3 shows the current Great Buddha of Kamakura without such a hall.

Figure 3 The Great Buddha of Kamakura

3.1 Geometric modeling

Figure 4 shows the flow of geometric modeling of the Great Buddha. The flow consists of scanning, alignment, and merging.

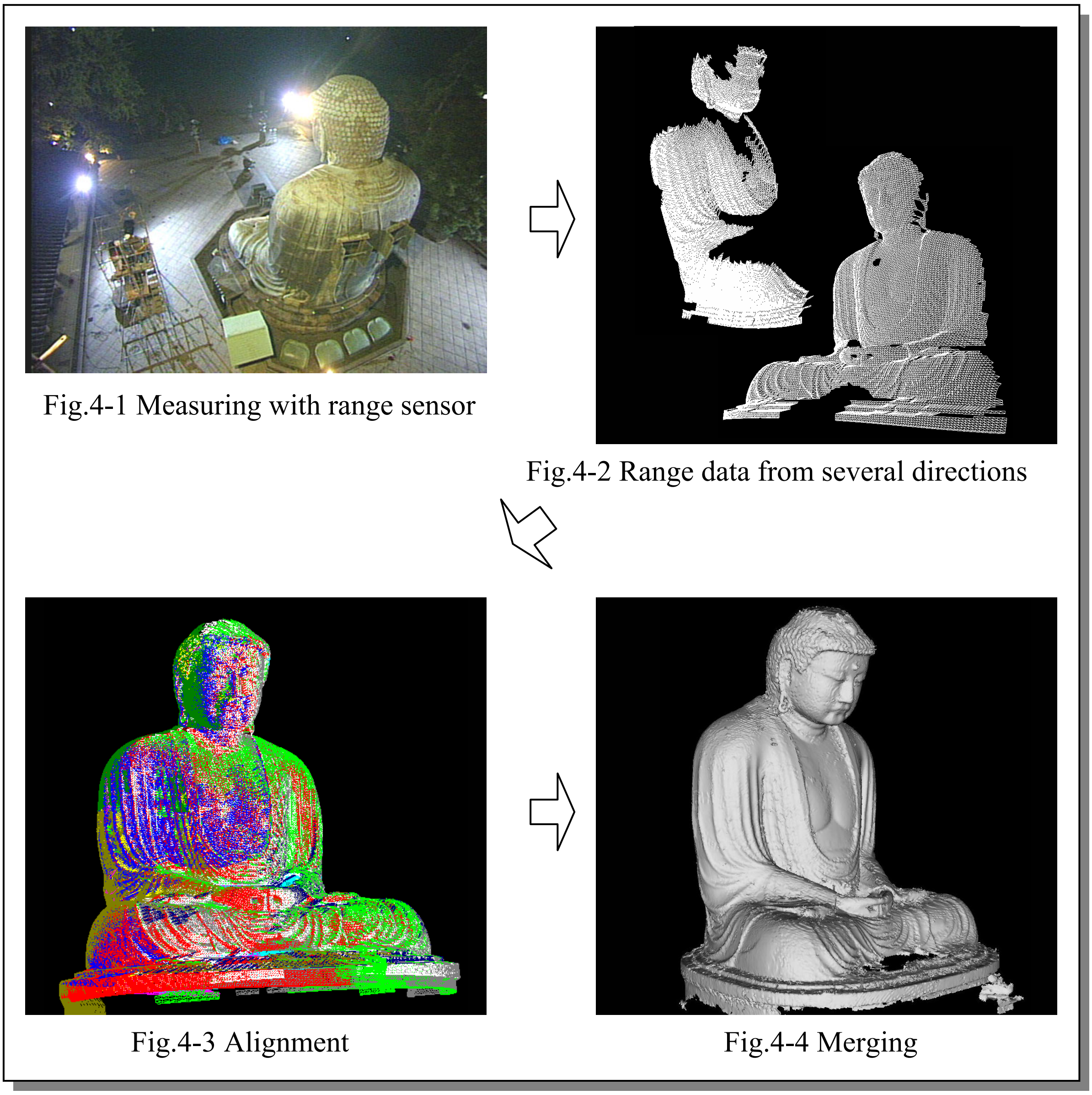

Figure 4 Modeling flow

Scanning

To obtain a virtual model of the Great Buddha, we first obtained twenty-four range images of the Buddha by using a Cyrax range scanner. In order to scan the upper part of the Buddha, we built a scaffold and mounted the sensor on it as shown in Figure 4-1. This work was done during the night to avoid sightseers.

Alignment

A simultaneous alignment method has been developed to avoid accumulation of errors. Traditional sequential methods such as ICP, align these meshes one by one, and progressively align a new partial mesh with previously aligned meshes. If a few partial meshes can cover an object, accumulation of alignment errors is relatively small and can be ignored. A sequential alignment works well. However, some cultural heritages are very large; we need more than twenty views. In this case, the error accumulation caused by sequential alignment methods is very large. Thus, by considering alignment of all the pairs simultaneously, we align all partial meshes so as to reduce the errors among all the pairs simultaneously.

Merging

After aligning all range images, a volumetric view-merging algorithm generates a consensus surface of the Buddha from them. Our method merges a set of range images into a volumetric implicit-surface representation which is converted to a surface mesh using a variant of the marching-cubes algorithm. Unlike previous techniques based on implicit-surface representations, our method estimates the signed distance to the object surface by finding a consensus of locally coherent observations of the surface. We utilize octrees to represent volumetric implicit surfaces -- effectively reducing the computation and memory requirements of the volumetric representation without sacrificing accuracy of the resulting surface.

We made up software in order to merge the aligned 20 range data. Since the input data is unpredictably huge, we built up a PC cluster to run this merging software, which parallel-processes the merging algorithm for saving the computation time and utilizing a large memory space of many PCs. We made one integrated digital Great Buddha with this software. Figure 4-4 shows the obtained virtual Buddha.

Once we obtain the geometric information of the Great Buddha, we can easily determine its cross-sectional shapes as shown in Figure 5. This is important information to compare with several shapes of the Great Buddha including Kamakura Buddha and Nara Buddha. We plan to scan the Great Buddha of Nara this fall.

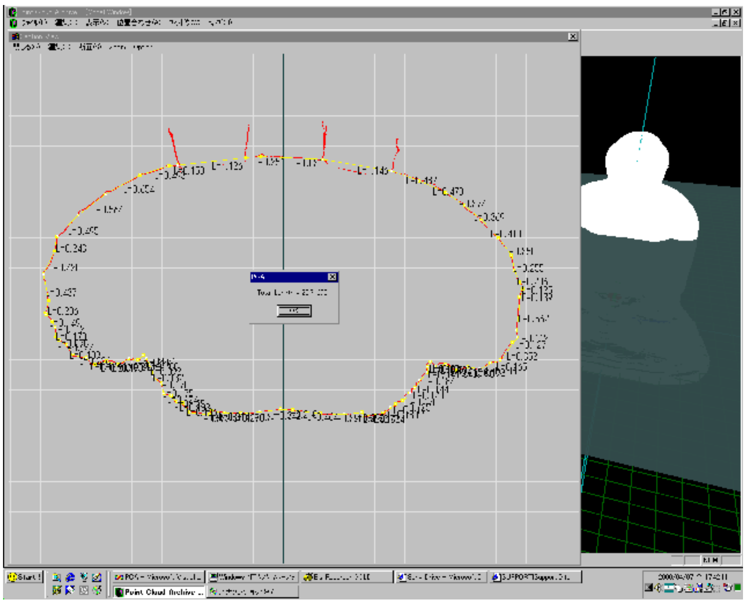

Figure 5 Cross-Sectional Shape of the Great Buddha

3.2 Photometric Modeling and Environmental Modeling

Using merged data of the Great Buddha, we made CG animation and finally produced a DVD work on the Great Buddha of Kamakura. The DVD work includes restored CG images of original wooden Buddha which was completed in 1243 and disappeared soon, as well as gold-leaf covered bronze Buddha which was made in 1260s. We also attempted to restore the Main Hall of the Great Buddha which was also completed in 1243.

Compared to the fact that the Great Buddha of Todai-ji temple in Nara was destroyed through earthquakes and wars, and only little part of the Great Buddha remains presently, the Great Buddha of Kamakura mostly remains since it was originally made, keeping enormous value as a national heritage. When we made CG animation of the Great Buddha of Kamakura, we reduced the merged data of the Great Buddha from around a few million polygons to 100 thousand polygons, and mapped it with textures of wood and gold-leaf.

Though the Great Buddha of Kamakura is now placed open-air, historical documents shows that the Main Hall of the Great Buddha once existed. According to available data, at least four halls were constructed for the Great Buddha. And after the hall was destroyed by the tidal wave in 1498, it was never rebuilt.

In restoring the Main Hall of the Great Buddha, we received advice and assistance from Professor Emeritus Kiyoshi Hirai of the Tokyo Institute of Technology, an expert on historical architecture. The Main Hall of the Great Buddha was designed in “Daibutsu-yo,” the same style as other great buildings of that time such as the Main Hall of Todai-ji temple in Nara which was reconstruced in Kamakura era. The design of the hall was based on drawings of the Main Hall at Todai-ji temple, that was renovated during the Kamakura period. Other models for the design included the Jodo-do hall of Jodo-ji temple in Hyogo. We modelled the data of the Main Hall using 3D CAD software ended up with 300 thousand poligons.

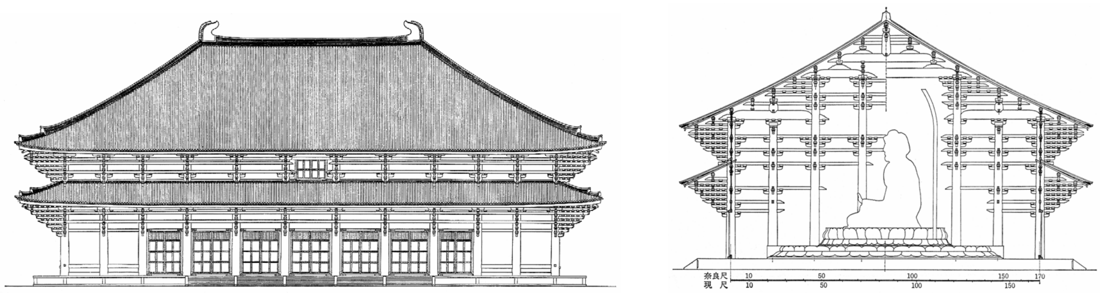

Figure 6 Drawings of Main Hall, Todai-ji, reconstructed in Kamakura era (by Minoru Ooka)

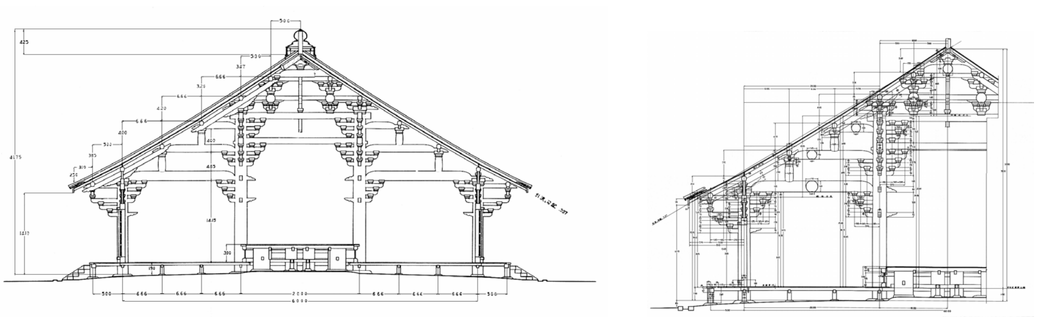

Figure 7 Drawings of Jodo-do, Jodo-ji

Figure 8 The Great Buddha of Kamakura in the Main Hall

In addition, in measurements taken in the autumn of 1999, data on the inside of the Great Buddha was also obtained and added to the outside data. At the same time, its thickness was measured to within an accuracy of less than one mm by using supersonic waves. In the big renovation project on the Great Buddha during the Showa era, the average thickness of the statue was estimated to be around 50mm based on its weight and surface area. This latest measurement showed that the most common thickness was 20-30 mm so it can be safely assumed that the overall thickness of the statue is quite uneven. By using the available data, more accurate three-dimensional data of the thickness of the statue was complied for taking countermeasures against corrosion and structural weakness in the Great Buddha.

4. Summary

This paper presents an overview of our efforts in modeling-from-realty to create virtual reality models of cultural heritage items through observation of real heritage items. These efforts span three aspects: how to create geometric models of virtual heritages; how to create photometric models of virtual heritages; and how to integrate such virtual heritages with real scenes.

We scanned the Great Buddha of Kamakura with Cyrax laser range sensor to obtain the exact geometrical information of the Buddha for the purpose of preserving its cultural heritage. We developed a system for obtaining the 3D geometric data automatically. The alignment software we developed sticks multiple range images taken by laser range sensor from many directions to the ideal position where those images represent the actual object. The program minimizes the geometrical difference of the covered part of each two images; this works simultaneously with all images until the whole differences minimize or until we think the differences are sufficiently minimized. We designed a program for merging the aligned range images into a mesh model. Since the aligned range images themselves have non-integrated geometric information, we cannot analyze the geometric features of the object. The merging software did a great job of obtaining the exact model of the scanned object. The old literature says that there once existed a building like the Great Buddha of Nara. We restored the Main Hall of the Great Buddha of Kamakura from many pieces of literature and many experts' technical knowledge, and then made up a computer graphic of how the Great Buddha looked like in 1267.

M. Levoy and his team members of Stanford University are also carrying out a project similar to ours [21]. They digitized some statues created by Michelangelo. However, those statues are relatively small (around 5m) when compared with the Great Buddha (around 15m). Due to that size difference, we encounter a large number of data points. We overcome this difficulty by using parallel merging algorithm. Another difference is that the Michelangelo statues are indoors and therefore less affected by sunlight. We have to employ a more powerful range sensor to measure the Great Buddha.

We plan to further extend this project through developing new sensors as well as refining algorithms in order to overcome problems encountered in completing the Great Buddha project.

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