SYSTEM FOR ASSISTING IN THE RESTORATION OF STONE WALLS, USING 3D MODELING

Syozo Nishumura,Keisuke Kimoto

Creative Department, Keisoku Research Consultant Co
1-665-1, Fukuda , Higashi-ku, Hiroshima, 732-0029, Japan
nisimura@krcnet.co.jp
kimoto@krcnet.co.jp

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ABSTRACT:

In order to make it easy to have agreements with masons and managers of cultural relics, "three-dimensional model locating system" is developed to help the project, which enables the remodeling analyses and the visualization of the construction and to presume line type in three-dimensional when a stone wall constructed. The data of the stones was collected by conducting a three-dimensional-laser scans on individual stones General Instructions

1. Introduction

The Honmaru "Nakanomon Gate stone wall" inside the Kokyo Higashi Gyoen Garden (Imperial Palace East Garden) was suffering from deformation, loose joints, damaged and delaminating stones, and other defects – all symptoms of its age. To ensure the safety of the wall, restoration work was carried out and was completed in March 2007. This stone wall, which used some of the largest stones (around 35 tons) in Edo Castle, is of the “kiri-komi-hagi” type (where the stones are very carefully shaped to interlock perfectly). This type of construction requires immense precision, given that the joint gaps are small and very little "clearance" is permissible. For the "restoration" of such a stone wall, one of the important issues to consider in planning the restoration is how to place the stones appropriately to restore the wall to the shape it had when it was originally constructed. It is also important to reflect the traditional skills of the original masons in the restoration design and stonework. Thus, to facilitate the participation of masons in the project and gain a mutual understanding with those in charge of cultural properties, we developed a "3D model placement system" which uses a 3D laser and other technologies to measure the individual stones constituting a stone wall and then creates 3D models for visualization so that a "restoration study" can be made.

To further reduce the time required, improve the quality of the generated models, and increase the design efficiency, we considered the addition of the following typical functions.

- Function for enabling analysis with only the stone shape data for the surface of a stone wall, to simplify the work process.
- Function for enabling the automatic generation of drawings up to the repair design drawings by tracing the stone shapes in three dimensions beforehand.
- Function whereby the steps leading up to the outline placement study can be performed with user-friendly 2D CAD processing.
- Function whereby the system can accommodate kiri-komi-hagi (stones shaped to interlock precisely) and uchi-komi-hagi (where the joint surfaces are processed to increase the points of contact).

Figure 1:Before the restoratioon

Figure 2:After the restoratioon

2. Overall configuration of stone wall restration system

The "3D model placement system" is an interactive system intended to assist in design and construction management such that if, for example, the crest of a stone interferes with the bottom of another when individual stones are assembled sequentially to simulate the restored shape, the interference can be reflected in the restoration study in real-time.

3. Stone wall restoration

3.1. Stone model measurement

Measurement techniques in stone wall restoration work include physical measurements and digital photogrammetry, and cases have been reported whereby the stone wall surfaces are measured using 3D laser scanners. In the past, restoration studies used patterns for individual stones that were created from drawings made through surveys, which were then assembled in a plane so that the overall shape was free from any defects, to create a restoration design drawing. These patterns were, however, so simple that the joint gaps could not be determined accurately, with the result that re-assembly would be carried out whenever necessary. A restoration study of a stone wall of the "kiri-komi-hagi" type, with small gaps and high precision, like the stone wall discussed here, requires not only information about the surface of the stone wall but also accurate shape measurements of the individual stones to such a level that any interference between the individual stones can be verified. The stone model measurements for this stone wall restoration used 3D laser measurements on the five sides of each of the stones, except the bottom, before and during the disassembly of the stone wall. The bottoms of the stones were measured with digital photogrammetry while the stones were slung from a crane. By creating each stone model based on the information thus collected, it is possible to perform stonework simulation.

Towards solutions to issues with generating stone models

When "stone models" are created from the point-group data obtained from 3D laser measurements only, the generated models can sometimes be smaller than they actually should be, because the peripheral edges of the stones are sometimes recognized as noise. Correction of this issue was extremely time consuming. Future improvements will include the ability to model stone shapes with high precision by complementing the laser measurements with photogrammetry.

Another improvement will be the capability to mark a stone wall with a grid beforehand to facilitate the checking of precision, thereby making it possible to reflect the check results on the work management during restoration.

Figure 3:3D laser measurement(Front side)

Figure 4:3D laser measurement(Back side)

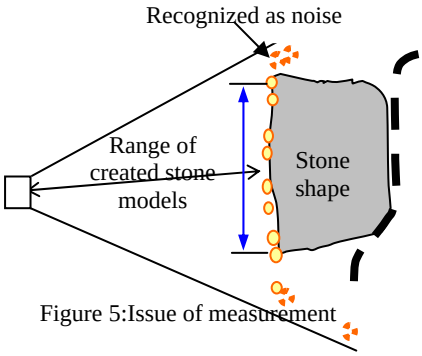
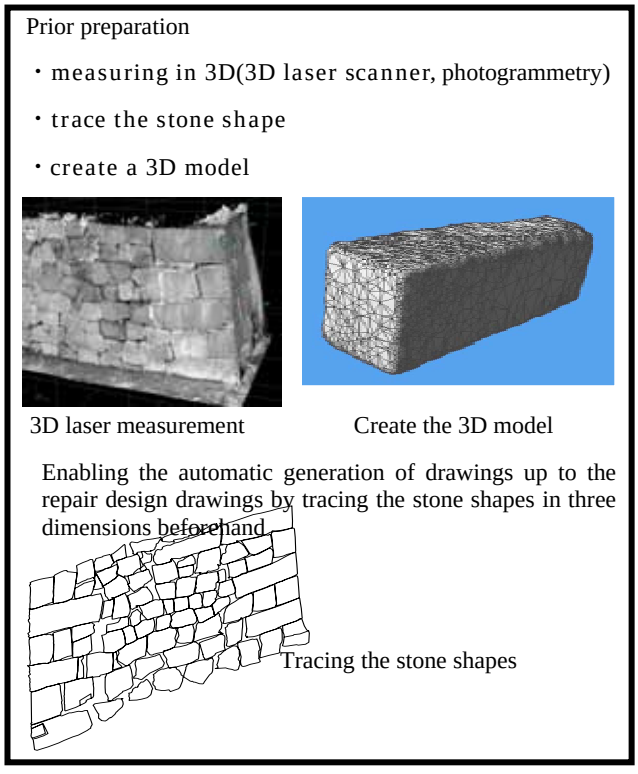


Figure 5:Issue of measurement

3.2. Interference assessment

The "stone wall restoration assistance system" is used to assemble individual stone models sequentially to simulate the restored shape and assess the interference status at that time. To satisfy the on-site needs of a stone wall restoration, the system provides a function whereby, in the event of the interference of any of the crests, sides, or bottoms of a stone, that interference can be reflected on the restoration study in real-time. A function for automatically performing stone wall design simulation is also supported.



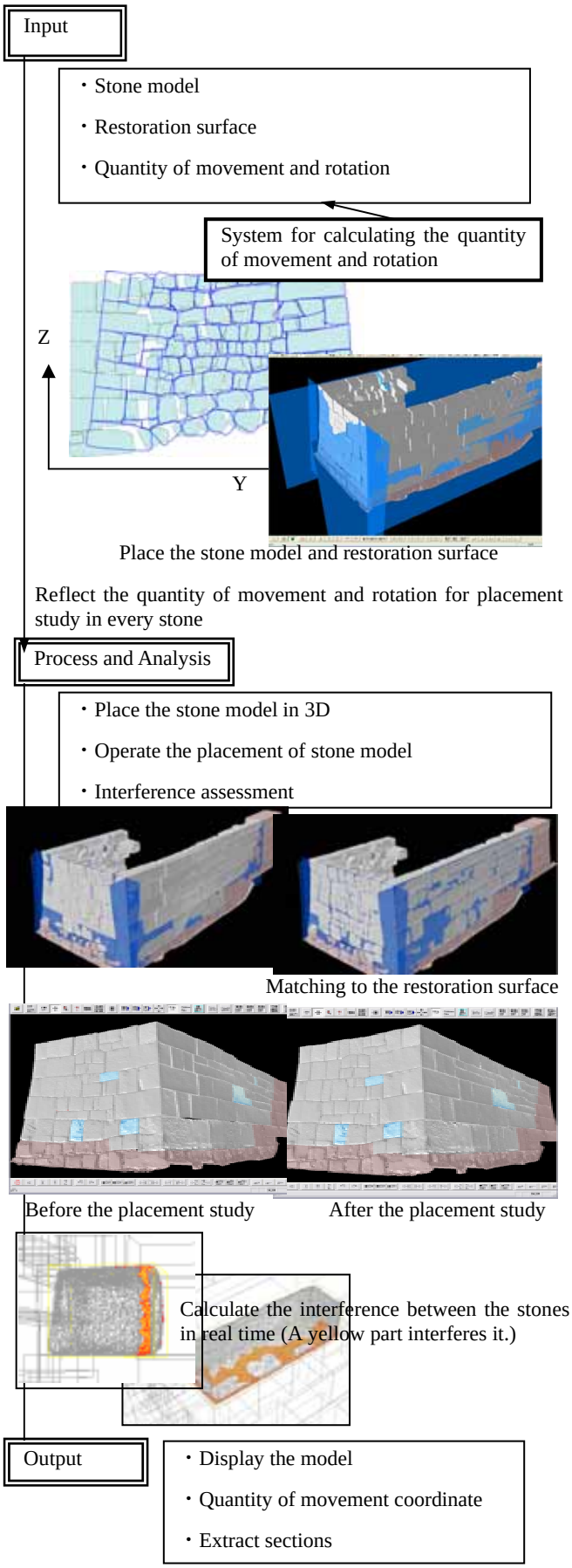


Figure 6: Flow of this System

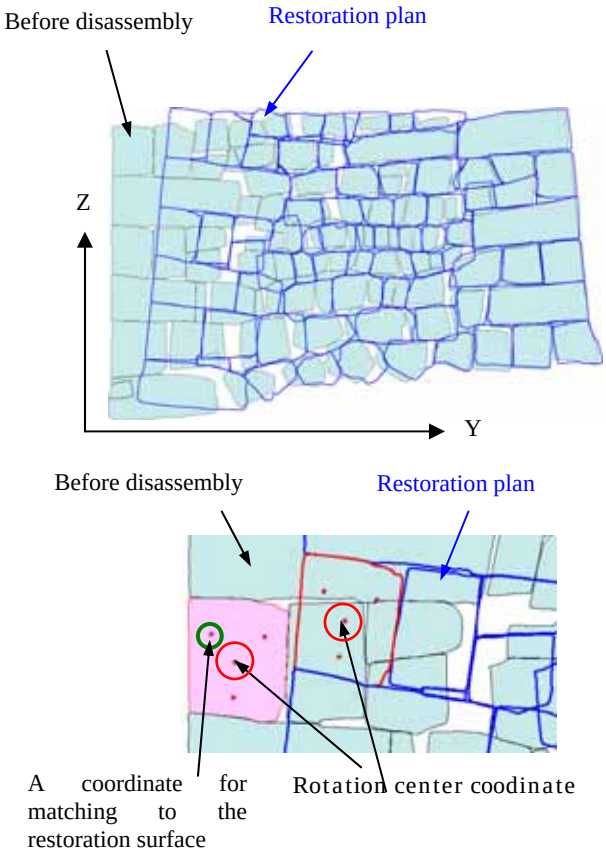


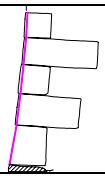
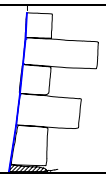
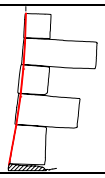
Figure 7: Prior study by 2D CAD

4. Restoration design-Study of the ridge line shapes of stone wall corners

In our study of restoration line shapes, we used the "3D model placement system" to study the placement of each stone in three dimensions by setting the gradients of the ridge lines of the corners of the stone wall while checking the planar shape, gradient, and warpage of the stone wall, as well as checking how the area to be restored would match the un-restored area from the viewpoint of appearance and how well it blends.

1. Plan to eliminate differences in level by keeping the current gradients intact
2. Plan to eliminate differences in level by partially modifying the gradients
3. Plan to calculate the gradients according to the "Ancestral Manuscripts of the Goto Family"

We studied the gradients of the ridge lines of these plans with 3D CG, and visualized and checked the resulting shapes, so that the gradient settings for plan 1 would make the stones fit well on each side, thus producing a stable shape.

	1	2	3
Stone wall corners and the ridge line			
Explanation	Keep the current gradients intact, and eliminate the difference	Modify the part of the gradients, and eliminate the difference	Calculate the gradients from the document of “Gotouke”
Diagrammatical view			
Assessment	At the top level of the stone wall, the corner stone leans inside, so the stone wall looks irregular	There are no interference between the stones, the stone wall don’t have any irregular	Stones at the 2nd level and 4th level are rotating, and there occurs interference.

5. Expansion into additional applications

3D laser measurement and the "3D model placement system" can be expanded into additional applications such as the visualization and display of construction processes and the central management of cultural property research results, because they offer innovative techniques for future stone wall restoration work.

1. Assistance in construction process and safety management

Capability to place and set individual stone models created in accordance with restoration work processes and display them with 3D CG.

2. Function for centrally managing records of cultural property research

Function for enabling the display of photos, comments, etc. by selecting from among placed three-dimensional stone models, in conjunction with a separately configured "stone research report management system", etc.

6. Conclusions

By using the "3D model placement system", it is possible to improve the quality of restoration work and to reduce the work of re-assembling stones that have been assembled incorrectly due to poor restoration design, thereby reducing the risk of going beyond the scheduled term of work and projected cost.

Because it can represent stones in three dimensions, the system enables the study of the order in which stones are assembled, stone wall reinforcement work, etc. interactively by looking at 3D images on the screen, so that it is effective not only for design but also for work planning and work management. Besides, the system enables the creation of a restoration plan by exchanging opinions with experienced masons in the planning phase, making it possible to incorporate their traditional skills at an early stage. By combining the most advanced three-dimensional simulation techniques with the skills of masons, and thus handing down stonework techniques to the next generation, the system can make a meaningful contribution to society. In addition, it can be expanded as an effective tool for designing the landscaping around a stone wall and planning the restoration of turrets, gates, and so on.

	Physical measurement	Digital photogrammetry	3D laser scanner
Summary	-Set lines horizontally and vertically with constant distance, and Make a measured drawing with the lines as standard.	-Taking a stereo photogrammetry, from the image, acquire an ortho image.	-Enable to acquire much 3D information directly in short time.
Stone measure ment			
Validity	-It enable to make a drawing with touching the object directly while understanding the state of the object.	-Enable to utilize the texture information of the stone surface as ortho image	-Enable to create the 3D model, from acquiring 3D information. -It can measure the shape of each stones effectively
Problem	-It takes much time and cost to set a scaffold. -It is high place work, so it is necessary to be careful -It is impossible to modify the drawing.(it is difficult to measure again.) -It is hard to measure the angle. -There will be unevenness between the investigator	-It needs manual operation to acquire the specific point from the data and its matching. It takes long time to acquire the 3D data. -It needs to set a datum point and measure every aspect, for the measurement of each stones.	-It is important to choice the appropriate machine, the density of the data and the number of measurement, not to cause a lack of the data or a hidden part.

7. Acknowledgment

This system was jointly developed in August 2005 by Shimizu Corporation and Keisoku Research Consultant, Co., in response to Shimizu Corporation's being assigned the "restoration work on the Honmaru Nakanomon Gate stone wall inside the Imperial Palace East Garden" from the Imperial Household Agency, for the purpose of assisting in work management.

During the development, we received tremendous cooperation from Mr. Koichi Tatsumi of the Imperial Household Agency and the chief on the site, Mr. Hiroyuki Yamauchi of Shimizu Corporation. We would like to express our sincere gratitude to them.

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