Real-Time 3D Digital Measurement of Archaeological Remains Using an Outdoor Laser Rangefinder: Examples Centering on the Ruins of Izumo Oyashiro Precincts, Oyashiro-cho, Shimane Prefecture, Japan

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Outline

One of the key roles of archeology is to attempt to extract the maximum amount of information from an archaeological object, site, or building, and to preserve its data value. However, since archaeologists have to deal with a tremendous quantity of remains, they are presently unable to record and catalog sufficient information given limited time and resources. Thus, it is justifiable to state that it is an urgent task to develop a measurement system that can obtain rapid and accurate data during excavation.

This paper proposes a new measurement system for archaeological remains using an outdoor laser rangefinder and describes attempts to use the laser rangefinder during actual excavation contexts.

1. Introduction

Cultural assets comprise important records of human history that leave signs of the past in the present and the future. Cultural assets are the common property of all humanity since it is the world that inherits them. It is our duty and responsibility, therefore, to retain and pass cultural assets to future generations.

Currently, over 10,000 excavations are in progress in Japan. Since we are faced with a tremendous number of remains, many sites and artifacts are destroyed or lost before they can be sufficiently studied. In addition, artifacts excavated often deteriorate. At present, it is difficult to record, catalogue, store, and treat each item due to the large amount of excavated remains. This often results in a progressive loss of the data value of each artifact.

On the other hand, there is a need to improve current excavation techniques and to streamline the overall research process, including the manual creation of drawings for physical features like dwellings and buildings, and material remains like artifacts. Additionally, the cataloguing, conservation, and analysis of remains is also quite time-consuming and labour intensive. There is an increasingly urgent need to reduce the time spent in excavation, measurement and cataloguing processes and to cut costs.

To prevent the loss of the data value of a buried cultural property, immediate data processing and conservation are major challenges.

Accordingly, we believe it is an urgent task to develop a new digital recording technology for efficiently collecting accurate data on the huge number of buried cultural properties and to make this technology known and available to archaeologists.

At present, the recording of relics is changing from plane-table surveying to photographic surveying. Digitization of measurement data and restoration in three dimensions has begun to be used, but this is still very costly. Most drawings are made by hand and 2D data is recorded using photographs.

Recently, a 3D shape-measuring device using infrared laser light (a laser rangefinder) which was originally usable only indoors has become applicable outdoors (1), and is starting to be used for some topographic surveys. We have been studying the creation of a 3D digital archive for cultural properties using this 3D shape-measuring device with the aim of conserving excavated remains. At the same time, we have also been conducting a prior study on artifact and building measurements (2) (3) (4). Last year and this year, we carried out preliminary experiments on measuring pillars in the ruins of Izumo Oyashiro precincts, Oyashiro-cho, Shimane prefecture. We confirmed that the laser rangefinder is an extremely effective tool for measuring historic architecture (5).

This paper aims to propose a new measurement system for historic/archaeological remains using an outdoor laser rangefinder, an instrument that has recently seen remarkable technological advances. In this paper we describe an experiment to measure a large stone structure from a prehistoric site using the laser rangefinder, an important element of the system.

2. Attempt to measure a large stone-built structure using an outdoor laser rangefinder

Prior to the development of a real-time relic measurement system, a test was conducted of application of the outdoor laser rangefinder to a large stone-built structure.

2-1. A Test of the Measurement System: A Large Stone Chamber Dug into the Side of a Hill

Measurement target

Ohno-kutsu mound located in Ryuhoku-cho, Kumamoto, is a round barrow, or burial mound, estimated to have been built in the late sixth century. The current size of this mound is about 39 m in diameter and 11.5 m in height. The entrance to the huge stone chamber opens on the southwest slope of the mound. The stone chamber is built with cut stones of Aso tuff. The total length is 12.4 m, and the burial chamber is 5.23 m long, 2.9 m wide, and 6.48 m high. Large stones are placed at the back wall and side wall, and relatively large stones are sequentially fed to the top, which is sealed with a single stone. A stone shelf is provided on the back wall. The front chamber is 2.3 m long, 2.16 m wide and 1.92 m high. This chamber is surrounded with huge stones. This stone chamber dug into a side of hill is the largest in Kyushu, and is also an important national monument.

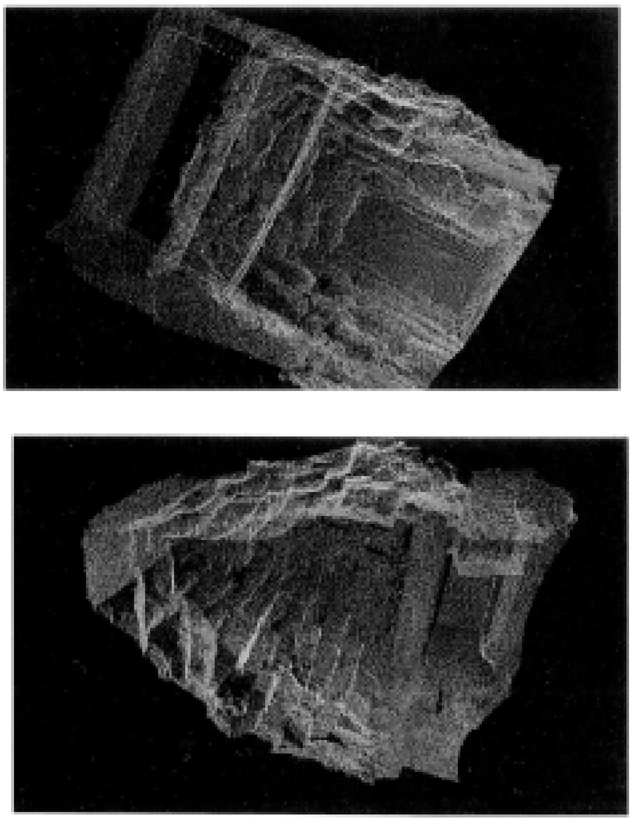

Fig.1 3D digital measurement of the burial chamber
(Top: Right side wall; Bottom: Left side wall)

Measurement Objective

The burial chamber itself is extremely large and the high risk of falling stones makes accurate measurement extremely dangerous. In addition, the state of collapse inside the stone chamber is difficult to identify quantitatively using two-dimensional photos or video material.

Accordingly, we applied 3D shape-data measurement using a non-contact laser rangefinder.

<u>Measuring instrument</u>

Measuring device: LPM-25HA (Riegl)

<u>Measurement method</u>

The burial chamber was measure by dividing it into front and rear parts.

<u>Measurement result</u>

Stonefall around the middle of the side wall was clearly identified. (Fig. 1)

Photo 1 Falling and sliding of the front wall of the burial chamber (measured using reflected light)

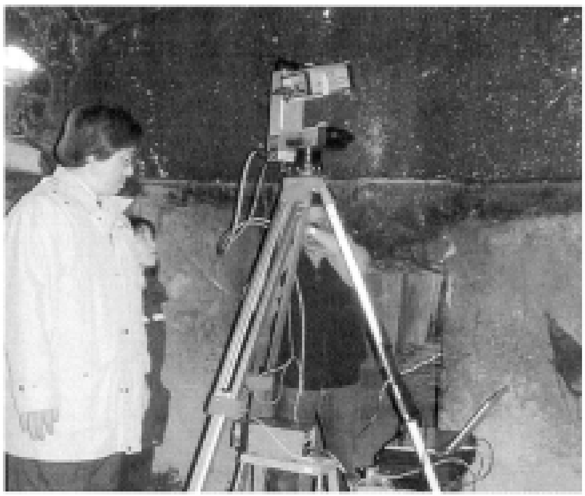

Photo 2 Measuring the stone chamber

2-2. Example of *magaibutsu* (a sculpture of the Buddha) (the large stone-built structure)

<u>Measurement target</u>

Magaibutsu, A sculpture of the Buddha in Oku-no-in, Saikyoji Temple, Tomita, Okawa-cho, Kagawa, is a *yakushi-nyorai* image that was carved on a bedrock of stone at the beginning of the Kamakura period. Up until now, its precise dimensions have not been measured, since the lower part is unidentifiable due to falling bedrock, but it is estimated to be about 5 m high.

Objective of measurement

The image of the Buddha is extremely large, and no accurate measurements have up to now been made. At present, falling stones make the manual recording of measurements extremely dangerous. We therefore applied 3D shape data measurement using the non-contact laser rangefinder.

Measuring instrument

Measuring device
Outline measurement: LMS-Z210 (Riegl)
Fine measurement: LPM-25HA (Riegl)

Measurement method

The large image of the Buddha stands on a slope, and thus the image was measured in four sections from all directions using a measuring instrument to first make a rough outline of the entire bedrock. Then, only the face where the *yakushi-nyorai* is carved was measured from two directions using a high-resolution measuring instrument.

Measurement result

We were able to clearly measure the *yakushi-nyorai* image, and the total length and dimensions of the face, that were previously unidentified, were confirmed.

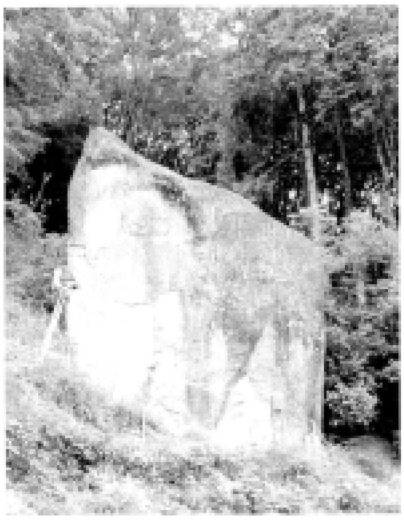

Photo 3 3D digital measurement of the carved Buddha

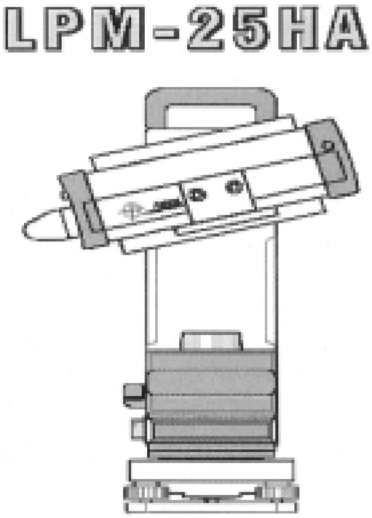

Fig. 2 Rangefinder for fine measurement

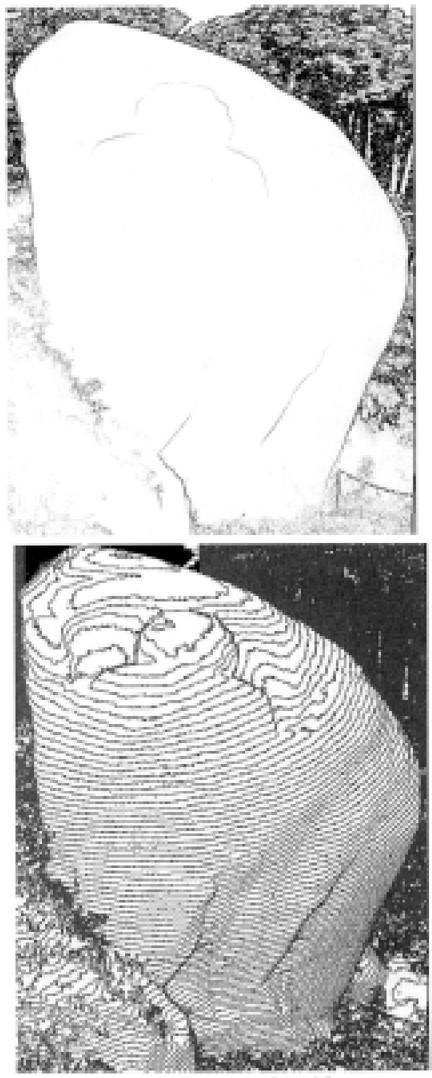

Fig. 3 Measurement result for the carved Buddha

(Top: shading; Bottom: moiré)

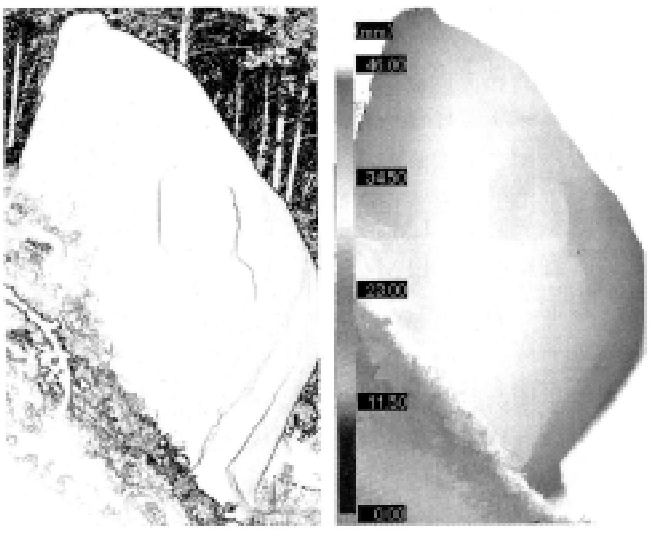

Fig. 4 Measurement result for the carved Buddha

(Left: shading; Right: moiré)

3. Proposal and Outline of Real-Time Measurement System for Historical Remains

3-1. Development Objectives

Currently, photographic surveying is rarely used for recording archaeological remains during the actual process of excavation. However, photographic surveying is used, in some cases, for mapping all the ruins after excavation is complete. In addition, the drawing of remains during excavation and excavation status charts are done manually. These operations take an extremely long time and also convey insufficient information. Hence, the measurement system using a laser rangefinder is very effective for archaeological contexts. This system enables real-time 3D digital measurement of remains while they are excavated layer by layer. Data is checked immediately after measurement so that the measured remains can be taken out immediately, allowing the dig to proceed to the next layer. The system has the potential to allow much more rapid excavation of remains. Application of this system enables fast excavation of easily deformed remains and creation of 3D data describing the state of excavation. Moreover, time-lapse visualization of the excavation and visualization and reproduction of the stratigraphic excavation state are facilitated after excavation, encouraging more effective use of the data.

3-2. Outline of the relic measurement system

Setting of relic framing points:

(1) Rough reference points for the measurement of the relic are set, and these reference points are measured using the total station.

(2) Rough digital measurement of the relic (Outline measurement)
The entire relic is measured using the laser rangefinder for outline measurement by including three or more reference points.

(3) Real-time digital measurement of the excavation state

Three or more reference points are set in the measuring field of view, and high-resolution data on the excavation state are created by digital measurement using the high-precision laser rangefinder (divided measurement depending on the area of the object being measured and measurement accuracy). The measurement data can be confirmed on the spot to carry out a series of digital measurements in real time for each layer.

(4) Data composition

Measured data is converted to DXF data, and data with different accuracy is converted based on the world coordinate system on CAD for composition.

4. A Real-time Measurement Test at the Izumo Oyashiro Shrine Pillars

4-1. Measurement target ruins

The ruins of Izumo Oyashiro precincts, Oyashiro-cho, Shimane, are famous for their huge pillars with the same design as those in a drawing of "*Kanawa no Gozouei Sashizu*" which describes ancient Izumo Oyashiro as a multi-story shrine. This documentation is attributed to Izumo no Kuni no Miyatsuko Senge family, the Chief Priest of Izumo Oyashiro. Each pillar, which consists of three small pillars, is 3 m in total diameter. They are the largest pillars excavated in Japan. In 2000, a survey was conducted to authenticate the pillars at three points in the survey area and to investigate the *uzubashira* pillar. In 2001, the *shinnomihashira* central pillar was investigated. We selected these ruins of Izumo Oyashiro precincts as a target for measurement.

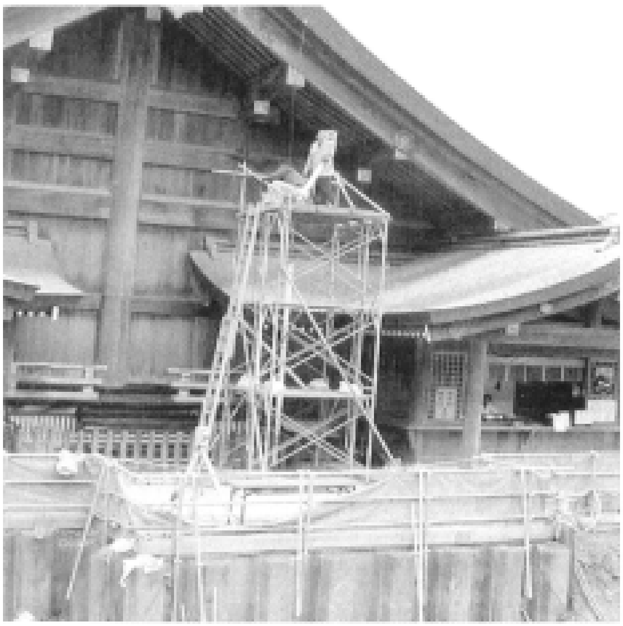

Photo 4 Measuring the ruins of Izumo Oyashiro precincts

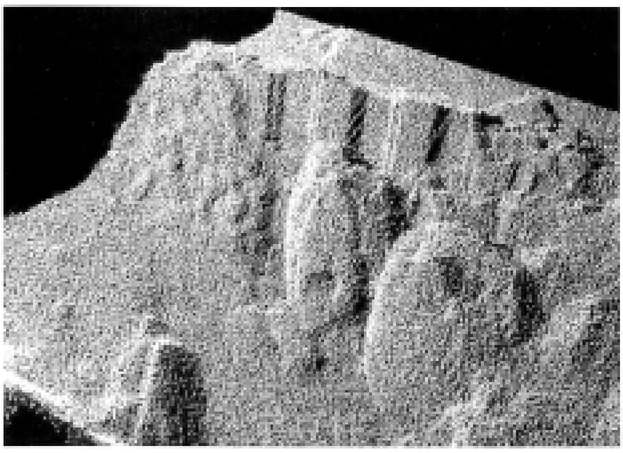

Fig. 5 Range image of the excavated uzubashira pillar

4-2. Selection of the laser rangefinder

We used two types of rangefinders: for outline measurement and fine measurement

- Rangefinder for outline measurement

We selected the Riegl LMS-Z210 based on the following elements:

(1) Measurement speed

(2) Viewing range (2 – 350 m)
(3) Operability (portability)
(4) Measurement accuracy (2.5 cm)
(5) For capturing color images simultaneously.

- Rangefinder for fine measurement

We selected the Riegl LPM-25HA based on the following elements:

(1) Measurement speed
(2) Viewing range (2 – 20 m)
(3) Operability (portability)
(4) Measurement accuracy (8 mm).

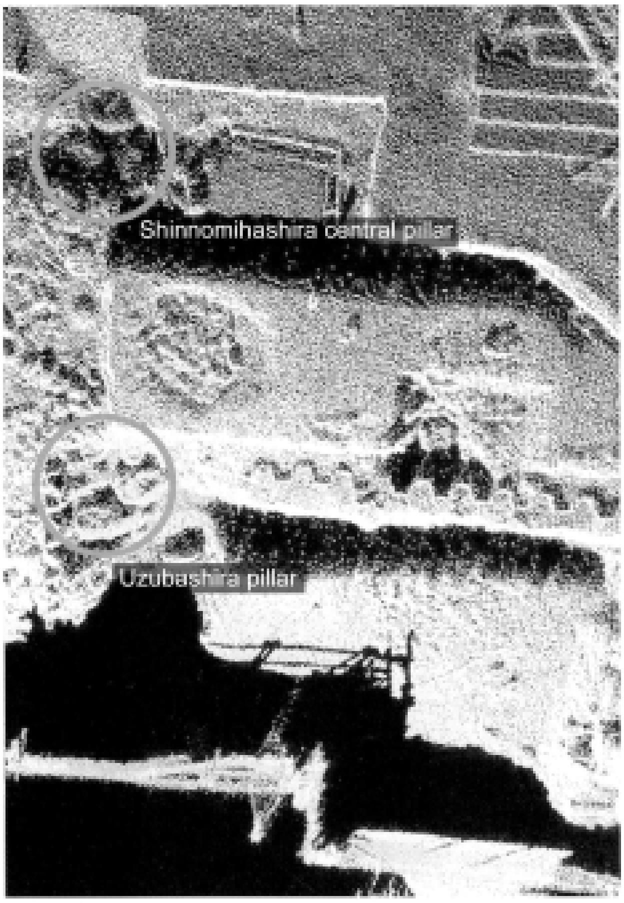

Fig. 6 Range image of the ruins of Izumo Oyashiro precincts

4-3. Measurement test of an excavated feature (FY 2000)

(1) Digital measurement of the entire ruin

The entire relic was measured using the laser rangefinder for an outline measurement.

The entire relic was measured from the tower and a sectional measurement was taken from four directions. More than three reference points were set within the viewing field, and the world coordinates of the reference points were measured by the total station.

(2) Fine measurement of the excavated *uzubashira* pillar

The measurement range was focused and the sectional measurement was conducted using the laser rangefinder for the outline measurement (since no rangefinder for fine measurement was available at the time). More than three reference points were set within the viewing field, and the target was measured by the total station.

The *uzubashira* pillar was also measured precisely using a Minolta VIVID700 at the same time.

4-4. Real-Time Measurement Test of an Archaeological Feature (FY 2001)

<u>Measurement schedule</u>

Measurements were taken three times chronologically: (1) Immediately after starting the survey (the uppermost face of *uragome* reinforcing stone*s*), (2) During the survey (during removal of the *uragome* stone*s*), and (3) While taking out the central pillar.

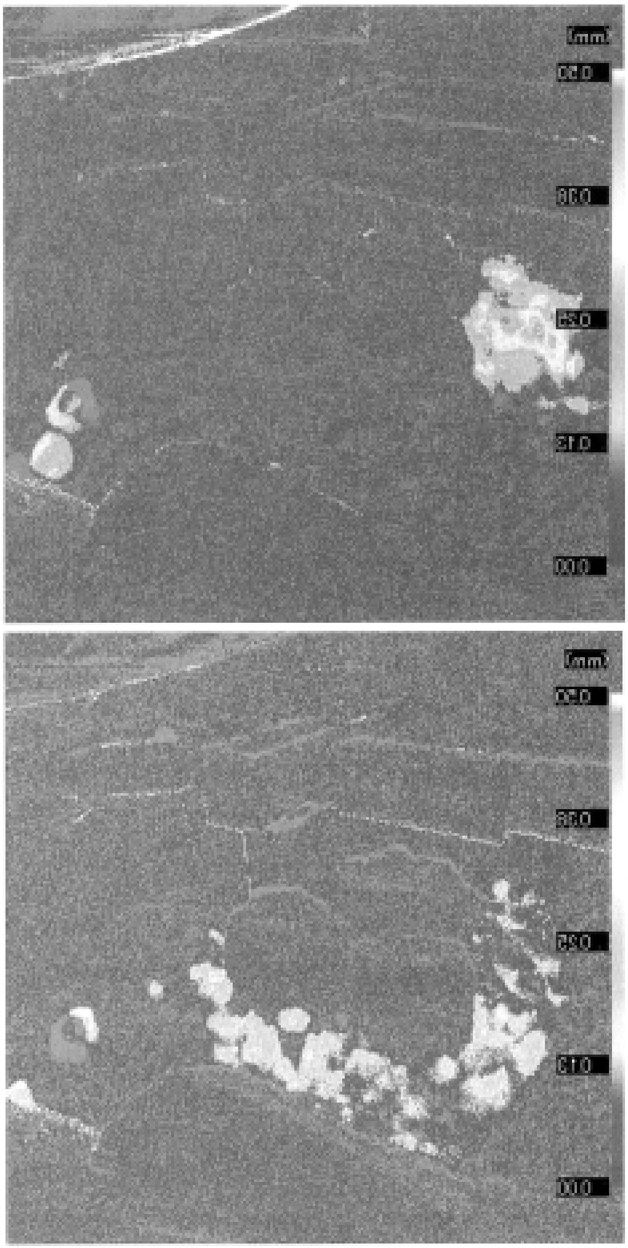

Fig. 7 Difference indication of range image
(Top: After removing 1/3 of the stones
Bottom: After removing all stones)

(1) Fine measurement immediately after starting the survey (uppermost face of the *uragome* stones)

Sectional measurement by focusing on the measuring range was conducted using LPM-25HA for fine measurement (Measurements from the north were not taken, since an H-steel girder was used to prevent tipping of the *yaita* (vertical sheathing) in the survey area). More than three reference points were set within the viewing field, and the target was measured by the total station.

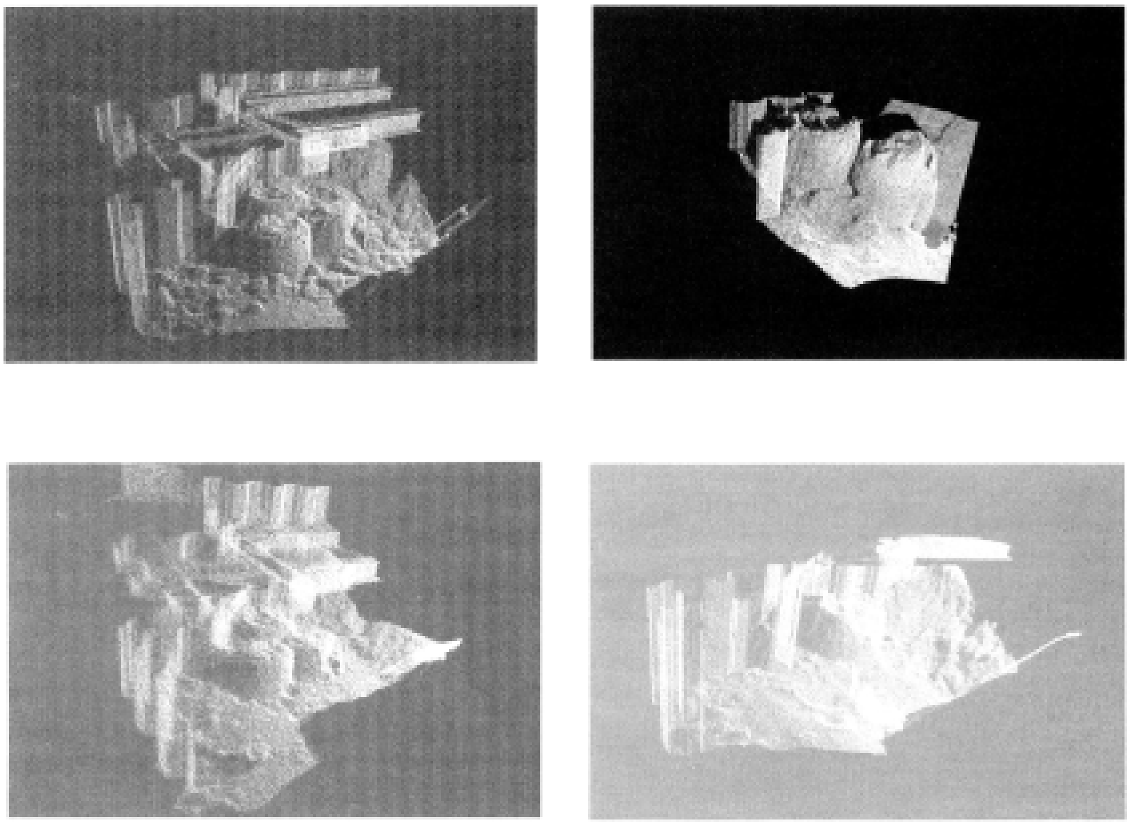

Fig. 8 Real-time measurements of the central pillar
Left top: Removing girder Left bottom: After removing girder
Right top: After removing one pillar Right bottom: After removing two pillar

(2) Real-time measurement during survey (during removal of the *uragome* stones). Removal of the *uragome* stones was digitally measured in real time.

On this occasion, the LMS-Z210HA was used for real-time measurement, since measurement speed was crucial.

The target was measured consecutively three times: before removing the stones, after removing 1/3 of the stones in the survey area, and after removing all the stones.

[Effect] In the conventional excavation process, a drawing of the stones underneath is made after removing each stone. Adopting real-time measurement of the feature, as in the type we propose, drastically cuts the time needed for this process. In addition, drawings during removal can be created stepwise, making it possible to identify the depth of the stone in the Z direction (embedded depth) by measuring the difference.

Real-time measurement during removal of the central pillar.

The removal process of the central pillar was measured digitally in real time. On this occasion, the LPM-25HA was used for real-time measurement with precision prioritized.

Measurements were taken three times consecutively before removal and after removing each pillar.

[Effect] In the conventional excavation process, a drawing is created every time after removing one pillar. Introduction of the real-time relic measurement can drastically reduce the work involved in this operation.

4-5. Future Tasks of Real-Time Feature Measurement

Hardware

Measuring device: For real-time measurement, a higher speed is required for the high precision laser rangefinder, and also RGB capability is required as a standard. Significant cost reduction is needed to enable its wider use.

System: A measurement system specifically designed for archaeological use needs to be developed.

Software

Data composition: Data was manually linked by finding characteristic points in the reflection tape and post treatment. Automated on-the-spot composition will be required for more rapid recording in the future.

Field notebook function: Each item needs to be identified in the layer containing each object and they also need to be linked to the 3D data. A function for inputting notes by pen on the texture captured through measurements, also needs to be added.

Data transmission: We wish to transmit captured data to remote locations for data confirmation (open excavation data). For this purpose, transmission capacity for large volumes of data is required.

Visualization: Expressions exclusive to archeology are needed to replace the present drawings and a method for disclosing such data via the Internet is required.

5. Conclusion

In this paper, we have tested and demonstrated that a new artifact measurement method using a laser rangefinder is effective for measuring archaeological remains.

We plan to develop a real-time measurement system for archaeological remains, and aim to develop and commercialize this system. Furthermore, in the near future we will design a measurement system specifically for archaeological use.

This year, we will continue on-site tests at other excavation sites to collect basic data for building a measurement system with a high level of practicality. Through the tests, we will also examine effective expression methods (visualization methods) of measured data and image processing methods including utilization.

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