Improvement of archaeological excavation efficiency using 3D photography and Total Stations

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ABSTRACT:

This paper focuses on the acceleration of the recording of archaeological excavation activities and also describes the efforts to digitize archaeological data.
In archaeological excavations, remains and artifacts are recorded using plane tables and batter boards. For recording soil layers and excavation planes, levels are used. The next step is taken after photographs are taken in the last phase of the previous step. The procedure has long been adopted in archaeological excavations without any problems. Rapid and accurate recording is now required in overseas surveys or because of cost increases. Three-dimensional (3D) digital photogrammetry and equipment like high performance digital scanners and Total Stations have recently been available at lower cost. Using the equipment now enables less expensive and more rapid excavations.
This paper describes the attempts made at Umm Qais, a site of ancient remains, in the Hashemite Kingdom of Jordan. Data on the positions of unearthed artifacts were recorded using self-tracking Total Station systems and data collectors. Then, 3D photographs were taken using a digital camera suspended from wires placed five meters above a grid. The artifacts were later numbered using a high performance ink jet printer and stored in bags. The process was repeated during the excavation.

1. INTRODUCTION

Accelerating recording during an archaeological excavation is becoming more important to reduce the time and cost required. There has recently been a drive toward the digitization of information in archeology as well as in other fields. Survey maps obtained by plane-table and offset surveys and conventional photogrammetric maps provide analog data. Digitizing the maps requires additional work. Digitizing all the data including the data on the positions of unearthed artifacts and the results of digital photogrammetry is another objective of the study described in this paper.

Chapter 2 describes surveys using digital plane tables to collect position data for remains and artifacts. Printing identification numbers on the artifacts using a high performance ink jet printer is also explained. Chapter 3 presents simple digital photogrammetry systems for remains used in the excavation in a grid or in a small area. Simple digital photogrammetry systems use a camera suspended from two poles or from a wire. For suspending a digital camera from a wire, installing a platform is required for placing the wire. Shown in Chapter 4 is digital photogrammetry using a balloon for grasping the unearthing of remains over a wide area. Wide-area photogrammetry is generally conducted using airplanes, radio-controlled helicopters and aerial photography. Balloons are superior in terms of precision, cost and time required for work.


Photo.1 Plane-table survey

2. SURVEY OF REMAINS AND ARTIFACTS

A conventional plane-table survey is shown in Photograph 1. The results of plane-table surveys depend greatly on the skill of the survey engineer. Skilled survey engineers can prepare high precision records efficiently. Approximately 20 measurement points can be plotted on the map per hour. The work requires two engineers. A survey using batter boards is shown in Photograph 2. In the survey, batter boards are fixed horizontally at the piles outside the grid. Leveling cords are placed to measure the dimensions of the remains or artifact for drawing it on paper. Benefits for the two methods include the low cost and freedom from malfunction of equipment, and easy acquisition of operation skills.

Digital plane-table systems using Total Station system and personal computers enable a single engineer to take measurements at 100 points per hour. Another advantage is no need of considering the scale. In plane-table surveys, the object is always drawn at its scale. Neither reducing nor increasing the scale is easy. Transcription and production of clean copies are required after the survey. In digital plane-table surveys, the scale can be specified freely in the output phase, and high precision is achieved. Survey work when a grit is excavated is shown in Photograph 3. This photograph shows the measurement of artifacts in a grit before excavation. When all the artifacts are measured, excavation is started. For measuring the position of an artifact, a pin-pole prism is installed at the center of the artifact and the X, Y and Z coordinates are measured using the Total Station. After measurements are completed, the artifact is picked and stored in a vinyl bag.

Fig. 1 shows the coordinates of the artifacts at the surface layer in grid G10 through a depth of 1000 mm. In the excavations to a depth of 1000 mm, each time excavation was done for a depth of approximately 100 mm, the artifacts unearthed were placed on the surface layer to measure their positions. Measurements were sometimes made after excavation for a depth of approximately 30 mm at certain frequencies of unearthing. Measurements were made for all the artifacts that were 10 mm wide and 10 mm long or larger. The total number of artifacts exceeded 6000 throughout the excavations. X marks indicate the positions of the artifacts with their identification number. For confirming the state, an enlarged map at point A is given in Fig. 2. The figure shows a two-dimensional map. For all the measurement points, Z coordinates have been identified that indicate vertical positions. The positions where all the artifacts were unearthed in the grid including the depth were known. A profile of the artifacts unearthed in grid G10 is shown in Fig. 3. Position data at nearly 6000 points is shown as in Fig. 1. The distribution of positions exhibits a moderate slope. In conventional surveys, measuring all the artifacts 10 mm wide and 10 mm long was impossible because measuring an extremely large number of artifacts would have been required. Digital plane-table surveys enable such measurement although assiduous work would be necessary. The significance of measuring such small artifacts, however, should be evaluated. It is still important that measuring artifacts in such a detail has become possible.

Fig. 4 shows a map of unearthed stone arrangements drawn in a digital plane-table survey. The stone arrangements are of various shapes including a rectangle. Stones outlined with curves are drawn using series of straight lines. Straight lines can later be replaced with curves passing measurement points. A shape closer to the real shape can be drawn. In this study, digital plane-table surveys were adopted for the measurement of stone arrangements. Photogrammetry may enable the recording of stone arrangements from an orthophotograph. Not only two-dimensional data but also data along the Z axis may be obtained.

Identification numbers used to be manually written on artifacts in felt pen or in paint. Letters were likely to be misread or disappeared on some objects. Using a printer as an alternative means solved the problem. Two methods were adopted for numbering unearthed artifacts. One was for directly assigning numbers to artifacts. Identifying numbers 4 mm x 20 mm were printed at a corner of an artifact using a high performance ink jet printer (Photograph 5). The other was for numbering vinyl bags for storing artifacts for sorting in the case where directly numbering artifacts smaller than 20 mm square was impossible. Direct numbering was possible for any objects 150 mm square or smaller regardless of shape. Numbers could be printed on

Photo.2 Survey using batter boards

Photo.3 Digital plane-table survey

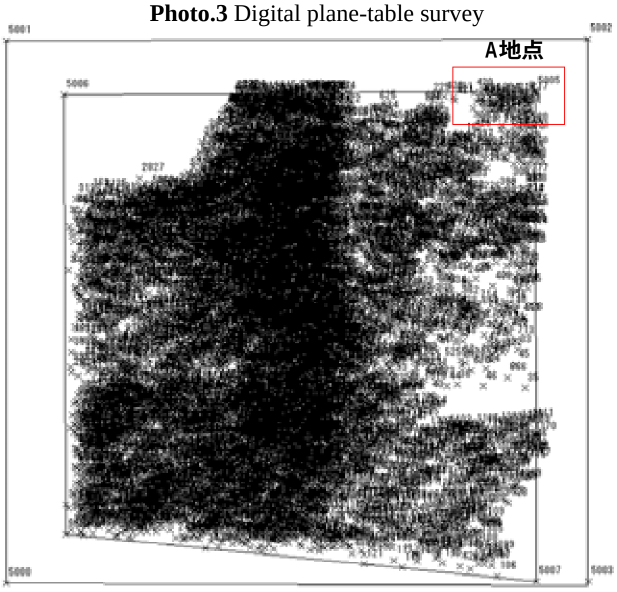

Fig. 1 Positions of artifacts in grid G10

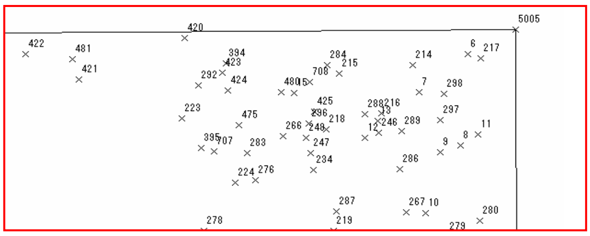

Fig. 2 Enlarged view of point A

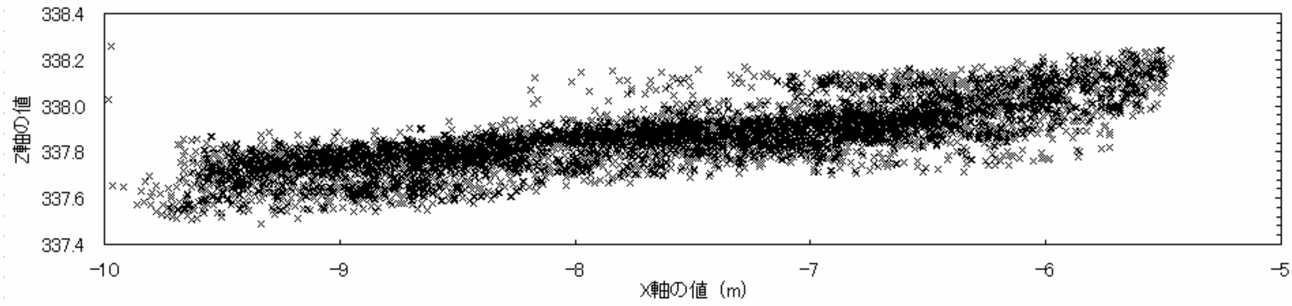

Fig. 3 Positions of artifacts in grid G10 (profile)

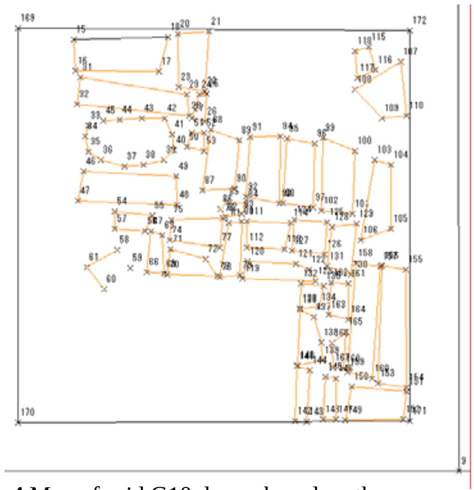

Fig. 4 Map of grid G10 drawn based on the results of digital plane-table surveys

Poto.4 Orthophotograph of grid G10

earthenware or objects of glass or stone. A KEYENCE MK-9000 high performance ink jet printer was used. Disadvantages include high cost, difficulty in acquiring consumables overseas and possibility of malfunction due to poor maintenance. Operating the machine every day keeps it in good condition. If operation is suspended for a long time, however, ink is consolidated and the machine may not be functioning properly.

3. SIMPLE PHOTOGRAMMETRY

Photogrammetry has technically been established in the mid-1900s. Data on the elevation and two-dimensional position can be obtained from a pair of stereo photographs and orthophotographs can be produced. With the wide use of digital cameras in recent years, three-dimensional information can be obtained based on digitized image data using application software for personal computers. Images based on the photographs taken by digital cameras are used, so neither projectors nor stereoplotters are required. Another benefit is photographic mosaics that can be created by connecting orthophotographs prepared based on images.

The digital imaging technology was used to quickly record the condition of excavation. In 3D photography, site work was completed with shooting using a digital camera and the measurement with the Total Station to obtain known points. In a grid 5 m square, taking four photographs and measuring at nine known points concluded the work. Two engineers finished the work in approximately half an hour. Upon completion of the work, the next round of excavation could be promptly started.

Photo.5 Numbering

Thus, the efficiency of excavation was greatly improved. In the past, solely acquiring a plan drawing used to take more than two hours although the time may have varied according to the skill of engineers and the quantity of artifacts. In conventional recording, photographs are also taken. They are, however, neither stereo photographs nor orthophotographs, so they provide no data on positions or variations of elevations.

At Umm Qais, two shooting methods were adopted for small-scale 3D surveys. A simpler method using two legs is shown in Photograph 6. Five-meter legs were used and a digital camera was attached at the top (Photograph 7). The digital camera was suspended using strings so as to be kept upright regardless of whether the legs were slightly sloped or not, and could take two-dimensional digital photographs. In the 3D survey system, keeping the camera upright is not necessarily required. To obtain better results, however, the camera was kept upright. The shutter was operated by remote control. One of the engineers who held the legs took photographs of objects at appropriate positions. Each engineer held a leg. The couple moved to another photographic site after shooting. Another method of shooting is shown in Photograph 8. Photographs were taken using a digital camera suspended from a wire placed between forms installed at both ends of an area where shooting took place. Installing forms required some time. Numerous grids could, however, be photographed efficiently. The method is fit for recording where large quantities of artifacts are excavated at shallow depths. The wire was placed above the centerline of the grid. The camera was moved laterally by operating the strings attached to the front and rear of the camera. An overlap of 60% was provided by stereo photographs constituting a pair. The area to be photographed was covered by pairs of stereo photographs. Then, the first and last photographs contained large space outside the area to be photographed. In the case where the amount of light was insufficient due to bad weather, the oscillation of the camera was minimized and photographs were taken when the oscillation ceased.

Photograph 9 is one of the photographs taken. The photograph was taken using two legs. No vivid color is represented because the photograph was taken in the strong sunshine during the daytime. An overlap of 60% was provided by the pair of photographs, indicating excellent shooting.

The photographs taken were input into a computer and subjected to 3D processing. The system used in this study was Topcon PI-3000. First, the camera was calibrated. Cameras, even of the same model, have varying lenses. Inputting the characteristics of the lens was necessary. Then, pairs of stereo photographs were inserted. The XYZ coordinates of measurement points, serving as known points, were input. In order to maintain compatibility of each pair of photographs, approximately six points were specified on the two photographs. At the completion of specifications, a switch was turned on to turn the data three-dimensional. Contours were later specified as an option so that the difference in elevation might be interpreted at the time of two-dimensional presentation.

Photo.6 Small-scale 3D photograph

Photo.7 Installing a camera

Photo.8 Medium-scale 3D photograph

Photo.9 3D photograph

Photo.10 Balloon for aerial photography

Photo.11 Aerial photography of an octagon

Photo.12 Photogrammetric mark

Photo.13 Aerial photographs

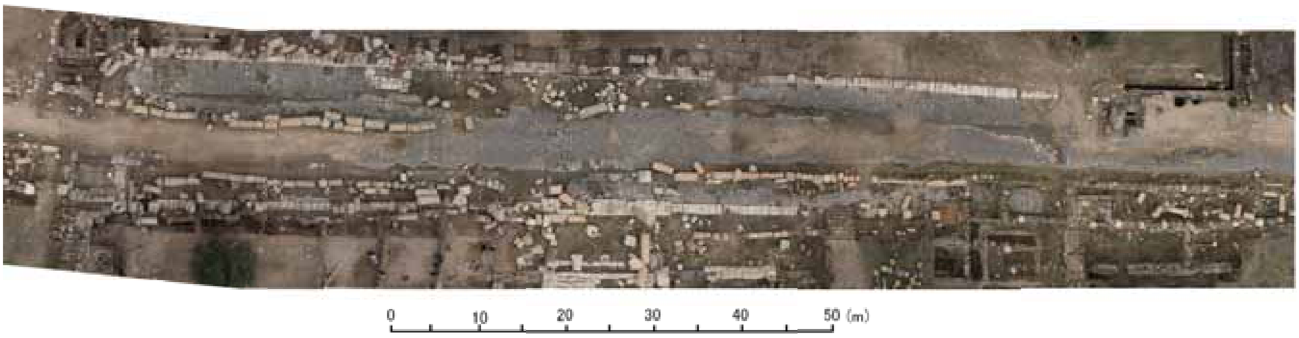

Photo.14 Orthophotograph

4. AERIAL PHOTOGRAMMETRY

For wide-area photogrammetry of the remains, a balloon was used. The balloon used in the shooting is shown in Photograph 10. The vinyl balloon was floated by injecting helium gas. A pan head was suspended below the center of the balloon. Attached to the pan head were a digital camera and a monitor camera for shooting the ground surface real-time. The position of shooting was controlled by operating the ropes attached at the front and the rear of the balloon. The rotation of the pan head was controlled by a radio-controlled device. Before shooting, photogrammetric marks were installed and XYZ 3D coordinates were measured using the Total Station. The balloon was led to a location where photographs should be taken while checking on a small monitor the images from the monitor camera on board the balloon. The balloon was guided so that six photogrammetric marks could be contained in a pair of photographs. As the balloon was oscillated by wind, excellent photographs were not always taken when the shutter was pressed even if the balloon was operated while confirming its position on the monitor. About three photographs were therefore taken above the area to be photographed and the best shot was adopted. An example of a photograph is shown in Photograph 11. The photographic subject was an octagon near the entry into a forum. The land was nearly flat in the vicinity. Based on the stereo photographs taken at different two-dimensional positions under a good shooting condition, 3D images were prepared using computer software. The photogrammetric marks that were important while preparing the images are shown in Photograph 12. It is important that photogrammetric marks are included in aerial photographs and that their positions are easily recognizable. The sizes of photogrammetric marks should be fit for the sizes of the photographs to be taken because extra-large marks are detrimental to the data on the objects.

A road of the Roman period was photographed (Photograph 13). Photographs were taken in the sequence from right to left on the upper level and then from right to left on the lower level. Only one of each pair of photographs is shown in the figure because of space limitations. A stone-paved road was photographed along the centerline. Objects on both sides of the road were photographed well in the direction of progress. Photographs were taken well nearly at right angles to the axis of the road. Shooting took place nearly at the same elevation. The area of photography was the same in all the photographs. Three to four photographs were taken at each point of shooting. Some were taken in a different direction than at right angles to the road axis. Taking several photographs is important. An orthophotograph prepared based on the aerial photography is given in Photograph 14. The objective of shooting was to record the present condition of a series of columns that were located sporadically as seen in the orthophotograph as the first step of restoration of the columns. Recording could be achieved accurately and quickly in the aerial photogrammetry using a helium gas balloon.

5. CONCLUSIONS

In this study, a comparison was made between a system for increasing the efficiency of recording in archaeological excavations and conventional systems. Conventional recording uses low-cost equipment, but the total cost is not always low if manpower cost and work efficiency are taken into consideration. The recording system presented in this paper requires equipment of relatively high cost, but is very cost effective because high precision and great efficiency can be achieved. The system also meets the recent demand for digitizing information. The archaeological excavation recording system presented in this paper is expected to be a standard in the future.