Progress in digital documentation for historical sites by photogrammetry and recent technology

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ABSTRACT: Documentation is a first step for the conservation of monuments and historical sites. Photogrammetry is a kind of the metric survey, and it has been applied to the many sites for the documentation. It has been developed in making topographic maps from aerial photographs historically. Stereo-photogrammetry can record the objects as three-dimensional (3-D) data. In this study, a few cases of digital photogrammetry with close-range photographs will be introduced. First Case is an earthen material in historical Buddhist monastery with a hand-held camera, second case is building stones which compose dry dock, and third case is artificial stone construction of lumberyard with quad-copter drone. UAV and SfM/MVS are very useful techniques for the documentation of monuments and historical sites.

1 INTRODUCTION

Documentation is a first step for the conservation of monuments and historical sites. In the field of Geo-technical engineering, the documentation has been focused on earthen materials and building stones, which compose the monuments and sites. There are some methods for the documentation of sites and monuments. It has been done by text, sketch, metric survey, photography and so on. Photogrammetry is a kind of the metric survey, and it has been developed in making topographic maps from aerial photographs historically. Stereo-photogrammetry can record the objects as three-dimensional (3-D) data. Around the 2000s, digital camera had been widespread all over the world and digital photogrammetry could be available. Using digital images, 3-D topographic models was able to be constructed in the computer with digital photogrammetric software. Around the 2010s, digital photography and computer vision technology had been combined and new technology had been created. It was called as Structure from Motion and Multi View Stereo (SfM/MVS).

Another progress is using unmanned aerial vehicle (UAV). Drone with quad-propellers is very popular all over the world now, and many aerial photographs have been applied to the historical sites with building stones and so on.

In this study, a few cases of digital photogrammetry will be introduced. First Case is an earthen material in historical Buddhist monastery (Fujii et al. 2009). Second case is building stones, which compose dry dock, by means of a hand-held camera (Fujii et al. 2018). In addition, third case is artificial stone construction of lumberyard by means of quad-copter drone.

2 PHOTOGRAMMETRY AND SFM/MVS TECHNIQUE

Photogrammetry is the science that measures objects on photographs (Linder 2003). Obviously, one can only get two-dimensional co-ordinates from a single photo, as it is a two-dimensional plane, but if two photos of the same object are taken from different directions, a stereoscopic picture is formed and three-dimensional co-ordinates of the object can be calculated.
A pair of analog stereo-photographs had been taken in the sites and 3-D topographic contours had been drawn with special equipment, such as stereo-plotter and analytical-plotter (Fujii & Hori 2004), before about year of 2000. The analytical-plotter was connected to a personal computer. And the computer was able to calculate ground co-ordination from photo co-ordination, and record the data of ground co-ordination. Historically, photogrammetry has been used to construct topographic maps from stereo-photographic pairs of aerial photographs. This technique could also be applied to close-range mapping with a hand-held camera (Atkinson 2003).

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Around the 2010s, digital photography and computer vision technology had been combined and new technology had been created. It was called as Structure from Motion and Multi View Stereo (SfM/MVS). Computer vision technology can be able to match the same points on multi-photographs automatically (Luhmann et al. 2014). Therefore, SfM/MVS makes us easier to make 3-D data from digital photographs, compare to classic photogrammetry.

3 APPLICATIONS TO THREE SITES

3.1 The case of Ajina Tepa

The monastery of Ajina Tepa Tajikistan, has been dated to between the 7th and 8th centuries AD and was excavated in the 1960s by Soviet archaeologists led by Boris Anatolevich Litvinskij (Litvinskij & Zejmal 2004). The site is entirely built of earth, part mud brick and part pakhsa (rammed earth, which is the compaction of earth between restraining surfaces or shutters). After the excavation, no appropriate preservation work was carried out and the site has deteriorated considerably as a result of weathering. The project ‘Preservation of the Buddhist Monastery of Ajina Tepa, Tajikistan, which had been launched by the UNESCO/Japan Trust Fund in central Asia, started in 2005 and completed in 2008 (Fujii et al. 2009). The main objectives of the project were: the scientific documentation of the site; the establishment of a master plan for the site; the application of appropriate conservation and maintenance schemes; the development of promotional activities at both national and international level; and the training of people in the maintenance, conservation, and monitoring of earthen archaeological sites.

Photogrammetric survey had been applied to the site for the scientific documentation, and the total area had been documented as a 3-Dimensional (3-D) surface model. 3DM Analyst, produced by ADAM Technology, had been sold by Kawaso Electric Industrial Co., Ltd. in Japan. This digital photogrammetric software could analyze a pair of stereo-photographs (Figure 1). Therefore, we took four pairs of stereo-photographs in which the stupa was taken from four directions, such as north, east, south, and west directions. After the 3-D point clouds had been generated from each

Figure 1. A pair of stereo-photographs of southwestern side of Stupa.
pair of stereo-photos (Figure 2). For making the total map of the site, 14 pairs of stereo-photographs were taken in the site of Ajina Tepa. These photographs almost cover the total area of Ajina Tepa. However, some areas in the photographs were hidden by high monument walls. For example, in a pair of overlapping photographs, which was taken from the top of the Stupa, some areas are hidden by the monument walls. Direct measurements were applied for the hidden areas with Total Station (metric survey equipment). Newly gained 3-D points were added into the photogrammetric data. Point clouds were combined and the 3D model (Figure 3) was generated by a software of Geographical Information System (GIS). Before 2010, it was difficult to operate UAV. In addition, it was the cases of remote area in which we had only limited equipment.

The survey results, 3D model (Figure 3) and mapping (Figure 4), had been useful for the establishment of a master plan for the site and the application of appropriate conservation and maintenance schemes. The site had successfully conserved with new mud bricks and mud plaster (Figure 5).
3.2 The case of Yokosuka Dry Dock

The Yokosuka Arsenal dry dock No. 1 is the oldest stone dock in Japan constructed during 1867–1871. It is composed of natural building stones, which were carved out of Shin-Komatsuishi Quaternary andesite. Building stones were used at the site and outside the dock as the seawall. The dock withstood the 1923 Great Kanto earthquake, sustaining no serious damage. Dry dock No. 1 is still in use today, but the surfaces of the building stones have been weathered by seawater and winds (Fujii et al. 2015). In addition, water is leaking from the mortar between the building stones in some areas near the gate.

Photogrammetric documentation had been conducted in May, 2013 (Fujii et al. 2018). The control points (markers) were marked with black square stickers (90 × 90 mm) with a 30-mm white circle in the center attached to the wall of the dock. A single lens reflex (SLR) camera with a fixed focal-length lens (c = 35 mm) was used to take multiple 2D images of the dock. Images of the south wall were taken from the top of the north wall at 5 m intervals (B = 5 m). Images of the north wall were taken from the top of the south wall (Fig. 6). The distance from the camera to each wall ranged from 20 to 25 m (H = 22.5). Approximately fifty photographs were taken of each wall, creating a sequence of about 100 photographs.

The ground sampling distance (GSD), which is the distance between each pixel center measured on the wall of the dock, is calculated as follows:

$$\sigma_{XY} = \frac{H}{c} \times \delta_{CCD}$$  \hspace{1cm} (1)

The camera sensor has a resolution ($\delta_{CCD}$) of 0.0079 mm. Therefore, GSD ($\sigma_{XY}$) is approximately 5 mm.
Table 1. Comparison between classic digital photogrammetry (CDP) and SfM/MVS software.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Number of Photos</th>
<th>Time for Analysis</th>
<th>RMS*</th>
<th>Set of control points</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDP</td>
<td>116 photos</td>
<td>about 5 days</td>
<td>10 mm</td>
<td>Manual</td>
</tr>
<tr>
<td>SfM/MVS</td>
<td>116 photos</td>
<td>about half a day</td>
<td>22 mm</td>
<td>Semi-automatic</td>
</tr>
</tbody>
</table>

*Camera calibration was conducted manually in CDP. It was simultaneously calculated during bundle adjustment in SfM/MVS.

The parameters for camera interior orientation and lens distortion were calculated using Topcon Image Master Calib software. Topcon Image Master Pro was used to generate the 3-D model of the site. Root Mean Square (RMS) of bundle adjustment is less than 10 mm (Fujii et al., 2018). It needed about 5 days to make the 3-D model.

About the 100 photographs and the coordinate of the control points has been still stored in a hard disk drive. Therefore, the same data has been analyzed by SfM/MVS software in 2021. Agisoft Metashpe has been used to generate the 3-D model of the site (Figure 6). RMS of bundle adjustment is about 22 mm. It needs about half a day to make the 3-D model. The parameters for camera interior orientation and lens distortion are calculated simultaneously when the bundle adjustment has been done. While, a half day is very reasonable compare to classic photogrammetric software analysis. A perspective view of the dock is shown in Figure 7. In addition, compared specification between classic photogrammetry and SfM/MVS is shown in table 1.

3.3 The case of Doudo Lumberyard

Doudo lumberyard is located along the Yahagi River in Toyota city, central Japan. This is very important, because it’s the only underwater lumberyard build in the middle of the river in Japan. It had been constructed in 1918. However, it had not been used since 1930 due to the construction of a dam upstream of it. It had been buried and not done proper maintenance. In 1988, the structures were excavated and restored by the cultural properties division of Toyota city.

DouDo lumberyard has been mainly constructed with artificial stone. Artificial stone construction is a civil engineering method created by HATTORI Choshichi. This method is based on “TATAKI”, a plastering technique traditionally used in Japan. The artificial stone was used for civil engineering constructions such as seawalls and embankments around 1900 before the spread of the reinforced concrete method. TATAKI is composed of a decomposed granite soil, quicklime, and water. A mixture of them is compacted tightly around the building stones (Takeuchi & Fujii 2022).

A quad-copter drone, DJI Phantom 4 Pro V2.0, was applied to the documentation of the site. About 230 aerial photographs were taken at the height of about 30 meters from the ground (Figure 8). The camera on the drone has 1-inch CMOS sensor with 20 megapixels, and the lens has focal length

Figure 8. 3-D point cloud of Doudo Lumberyard vie from the southeast. Red line merged squares show camera positions of UAV.
of 8.8 mm. Before taking the aerial photographs, 12 control points were set on all over the site, and the coordinates of them were measured by a Total Station (computer-aided transit).

The camera sensor has a resolution ($\delta_{\text{CCD}}$) of 0.0024 mm. Therefore, GSD ($\sigma_{XY}$) is calculated approximately 8 mm form the equation (1). The SfM/MVS software (Agisoft Metashpe) has been used to generate the 3-D model of the site (Figure 9). RMS of bundle adjustment is less than 15 mm. Trial comparison has been conducted the current 3-D model and the historical documentations (Takeuchi & Fujii 2022).

![Figure 9. Perspective view of the 3-D texture model viewed from south east direction. The size of the lumberyard, the length 100 m, the width 50 m, and depth is about 10 m.](image)

4 SUMMARY AND CONCLUSIONS

Photogrammetry is one of the effective techniques for the documentation of monuments and historic sites constructed with earthen materials and building stones. The technique has been applied to many historic sites by close-range photography with hand held-cameras. Recently, un-manned aerial vehicle, which includes drone, is very useful equipment to take aerial photographs. In addition, the technique of SfM/MVS is suitable to analyze those photographs. The recent technique might be much applied to future projects.

REFERENCES