Recent trend about photogrammetry and computer vision: 3-D visualization from multiple 2-D images and application to Yokosuka Arsenal Dry Dock

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Abstract

Both Photogrammetry and Structure from Motion (SfM) are techniques that can generate three-dimensional (3-D) visualization from multiple two-dimensional (2-D) images. Historically, photogrammetry has been developed to make topographic maps from aerial photographs. Recently, this technique has been completely developed as digital photogrammetry, and it has been applied to various objects. On the other hand, SfM is a very new technique which has been developed in the field of computer vision. Both techniques were applied to Yokosuka Arsenal No.1 Dry Dock, and complete 3-D model was generated from multiple 2-D images. Both techniques are useful to make 3-D surface model of the object. For the technique of photogrammetry, it is needed to put control points on the object to calculate the camera positions and rotations. On the other hand, it is very easy for SfM to make a 3-D model. Because control points are automatically detected in 2-D images by the method of computer vision. The progress of these techniques, related to photogrammetry and computer vision, are very fast. It could be rightly applied to the objects related to engineering geology, and should contribute to this field.

Keywords: digital camera, image analysis, Structure from Motion, Bundle Adjustment

1. Introduction

Many historical monuments and structures are composed of rock materials, for example stone walls and tombstone. Those, “stone cultural properties” have been deteriorated by weathering and erosion through many years. Engineering Geologist can contribute to conservation and preservation for those stone cultural properties.

Generally archaeological investigation is started by documentation for cultural properties. Conventional archaeological documentation has been conducted by photography, sketch, and plane table surveying. Recently survey equipment and method has been developed dramatically. Therefore, three-dimensional (3-D) documentation has been applied to many sites and monuments by the method of laser beam profiler and image measurement. These new technologies need much time and some work functions compared to conventional methods. However, documentation and measurement can be conducted simultaneously with these techniques. Application of these technologies are also able to contribute to analyze the mechanism of weathering and erosion for historical sites and monuments (Fujii et al., 2009).

In this article, photogrammetry and Structure from Motion (SfM) have been applied to a historical structure with building stones. Both techniques are kinds of image analysis for measurement, which generate 3-D models from multiple 2-D images. Historical structure is Yokosuka Arsenal No. 1 Dry Dock, which is constructed about 150 years ago with andesitic building stones. Some building stones have been damaged by salt weathering, and the surfaces are deteriorated by erosion (Fujii et al., 2014).

2. Method

In this section, introductory explanations for photogrammetry and SfM are described in following subsections.

2.1 Photogrammetry

Photogrammetry is a science to measure objects on photographs (Linder 2003). Obviously, a single photograph has only two-dimensional information, as it is a two-dimensional plane. If two photographs of the same object are taken from different directions and locations, a stereoscopic picture is formed and 3-D information of the object can be gain. The photographs are called as a pair of stereo-photographs.

Historically, photogrammetry has been used to construct topographic maps from stereo-photographic pairs of aerial photographs. This technique can also be applied to close-range mapping with a hand-held camera (Atkinson 2003).

Data for camera locations and directions when taking the photographs are used to get the three-dimensional information. However, it is very difficult to get accurate locations and directions at the same time when taking the photographs. Before taking the photographs, many control points were put on the surface of the object. Generally, coordinates of the control points essential to the photogrammetric evaluation were determined by the use of a geodetic Total Station (TS). The camera positions and directions can be inversely calculated from the control points by means of a least squares adjustment. This technique is called as "bundle adjustment". 3-D digital photogrammetric software is employed for bundle adjustment and to get 3-D information on the surface of the object.

2.2 Structure from Motion

The last three decades have seen a dramatic increase in the capabilities of 3-D computer vision algorithms, which include advances in feature correspondence, structure from motion, and image-based modeling (Snavely et al., 2007). The development of effective structure from motion techniques, which aim to simultaneously reconstruct the unknown 3-D scene structure and camera locations and orientations from a set of feature correspondences has been successfully used.

More recently, related techniques from photogrammetry such as bundle adjustment have made their way into computer vision and are now regarded as the standard for performing optimal 3-D reconstruction from correspondences (Snavely et al., 2007).

Feature detection and matching techniques has been especially developed recently, and wide baseline matching, i.e., the automatic matching of images taken from widely different views can be succeed (Snavely et al., 2007). Therefore, detecting the control points for photogrammetry can be automatically conducted by means of SfM.

3. Application to Yokosuka Arsenal No.1 Dry Dock

There are 6 dry docks in the United States Naval Base, Yokosuka city, Japan. Three of them, from No. 1 to No. 3, have been constructed with building stones. The oldest one is dry dock No. 1 (Fig. 1: this photo was taken from the top of the gate) which had been constructed from 1867 to 1871 under the supervision of French engineers, Verny and Florent. It is one of the most important constructions in Japan,

Fig. 1 Yokosuka Arsenal No.1 Dry Dock

because it's the oldest dry dock with building stones. In addition, its construction methods and techniques have been applied to the following construction of Japanese dry docks. The size of the dock is 140 meters length, 30 meters width and 10 meters depth (see Fig.5; result from SfM analysis).

The dry dock No. 1 is still in use today. However, the surfaces of building stones have been weathered by seawater and winds. In addition, water leakage from the joints of the building stones can be identified in some areas near the gate. It is needed to document the dock and survey its stability to preserve and conserve it for the future.

3.1 Case of Photogrammetry

Fig. 2 shows a flow chart for the photogrammetric analysis. Fig. 3 shows planning to take photographs (multiple 2-D images) of the dry dock. Control Points are sticker-type ones. Each one is 90 mm size black-color square with 30 mm size white-color circle in the center (Fig.3). They can stick on the wall of the dock (Fig.2-I). Single Lens Reflex Camera with fixed focal length lens (c = 35 mm) was used for taking multiple 2-D images of the dock (Fig.2-II). Multiple 2-D images of the south wall had been taken from the top of the north wall at 5 meters intervals (B = 5 m).

I: Setting of Control Points
(It is not always necessary)
↓
II: Taking Photographs
(Photo-Sequences)
↓
III: Detecting Control Points
(Matching Same Points on Photo-Sequences)
↓
IV: Bundle Adjustment
(Calculating Camera Locations and Directions)
↓
V: Image-Based Modeling
(3-D Visualization)

Fig. 2 Flow chart for photogrammetry

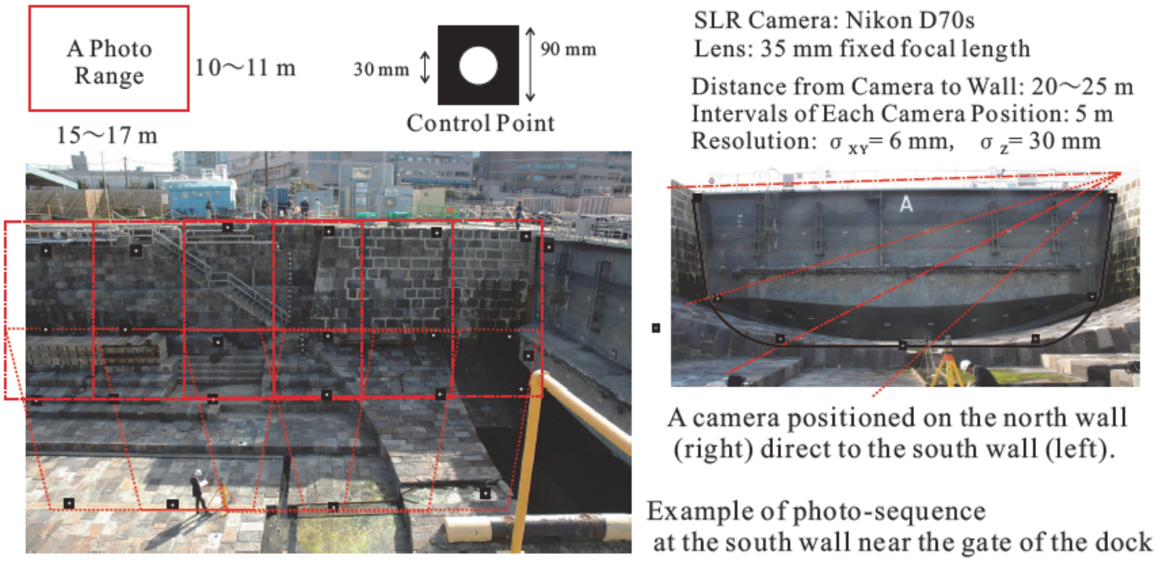

Fig. 3 Plan to take photographs (photo-sequence) of the dry dock

2-D images of the north wall had been taken from the top of the south wall. Distance from camera locations to each wall is from 20 to 25 meters (H = 22.5). About 50 photographs had been taken for each wall. Therefore, about 100 photographs had been totally taken as photo-sequence of the dock.

The resolution of photogrammetry is calculated as follows,

$$\sigma_{XY} = H / c \times \delta_{CCD} \quad (1)$$

$$\sigma_Z = H / B \times \sigma_{XY} \quad (2)$$

In these equations, σ_{XY} is the resolution parallel to the photo-plane, σ_Z is the resolution vertical to the photo-plane. The sensor of the camera (δ_{CCD}) has a resolution of 0.0079 mm. Therefore σ_{XY} is about 5 mm, and σ_Z is about 23 mm.

Multiple 2-D images had been installed into a computer and analyzed by a commercial photogrammetric software. Control points which were included in photographs were detected on the photographs (Fig.2-III). Camera locations and directions could be inversely calculated by bundle adjustment (Fig.2-IV), and the residual error is less than 10 mm. The photogrammetric software can match the same position on multiple 2-D images and generate 3-D points in the computer (Fig.2-V). Finally, 3-D surface model could be generated and photo-images were put on the surface (Fig. 4).

3.2 Case of Structure from Motion

Workflow of SfM is very similar to the case of photogrammetry. However control points are automatically detected by image matching in SfM software (Fig.2-III). In this research case, “VisualSFM” was applied to analyze the same multiple 2-D images of the dock. VisualSFM is a GUI application, made by Dr. Changchang Wu, for 3-D reconstruction of multiple photo-sequence using

Fig. 4 3-D surface model of the dry dock by photogrammetry

SfM. The reconstruction system integrates some programs including SIFT, Bundle Adjustment and so on. VisualSFM is a non-commercial program. It can be downloaded from the web site of Dr. Wu. Fig. 5 shows the 3-D reconstruction result of multiple camera locations and 3-D point cloud of the dock. To generate more dense reconstruction of point cloud or 3-D surface model of the dock, it is needed another software or program.

4. Summary and Conclusion

Historically, photogrammetry had been used to construct topographic maps from aerial photographs. Recently aerial laser beam profiler has been used instead of photogrammetry. In the last decade terrestrial laser beam equipment has become reasonable price and convenient. Therefore the use of photogrammetry had been declined with increasing demand of laser beam profiler. However the development of computer vision science enable us to use image analysis more reasonable. In addition, it’s much easier to use compare to traditional photogrammetry. Because the control points can be automatically detected by SfM. However the result of bundle adjustment (residual error) is not known in the program of VisualSfM.

Development of the technology is very fast. Therefore we should follow the progress of these technique related to photogrammetry and computer vision. In addition, it should be applied to and contribute to the fields of engineering geology.

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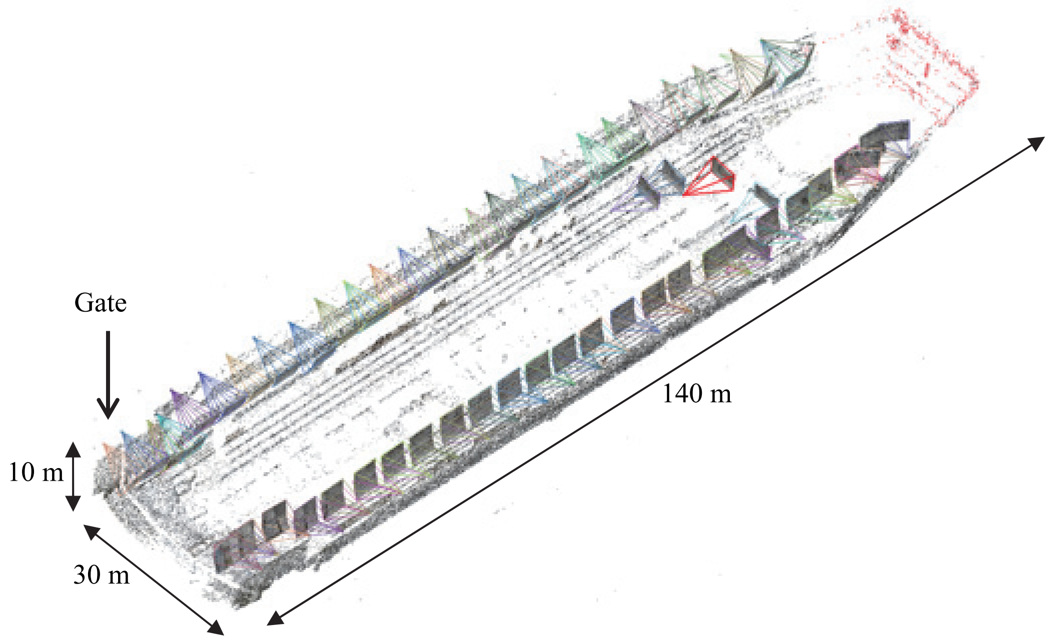

Fig. 5 Perspective reconstruction view of the dry dock photo-sequence by SfM