CAMERA PATH DESIGN AND EVALUATION IN GROUND-BASED IMAGE ACQUISITION FOR STRUCTURE FROM MOTION AND 3D MODELING

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ABSTRACT: The Structure from Motion (SfM) is a useful approach to generate 3D data for various, such as infrastructure inspections, disaster monitoring and archaeological surveys. Images taken from random viewpoints can be used in the SfM processing. However, a plenty of processing time is required to detect feature points and corresponded points from images in the Scale-Invariant Feature Transform (SIFT) procedure. When the number of images for the SfM is minimized, the efficiency in SfM processing can be improved. Moreover, the minimization of the number of images can achieve a shorter flight time in UAV operation. Therefore, we focus on a camera path design is required to improve the efficiency in images acquisition for SfM processing. In this research, we proposed a camera path design to improve the efficiency in the SfM for a reconstruction of complex objects. We conducted experiments to verify our camera path designs for several image acquisition patterns. Through our experiments, we evaluated our camera path designs with the number of images for the SfM and point cloud density.

1. INTRODUCTION

There are two major approaches in 3D measurements. The first approach is laser scanning. A laser scanner can acquire dense point clouds easily. However, laser scanners for surveys are generally expensive. The second approach is Photogrammetry and image-based modeling. Recently, there are many studies related to 3D modeling using images. We can easily generate 3D models with Structure from Motion (SfM) software products, without knowledge of Photogrammetry. Image-based 3D models are used for map services, urban planning, disaster prevention, building information modeling, construction information modeling, and augmented reality application. Conventional SfM approaches require images acquired from various viewpoints to reconstruct a 3D model without occlusion. The SfM is mainly consisted of image-based matching with Scale-Invariant Feature Transform (SIFT).
When we generate 3D models of objects, camera positions should be estimated in a SfM process procedure. The estimation result and processing time depend on the number of input images. Although accurate result can be obtained using many input images, the efficiency in image acquisition and processing would be worsen.We conducted preliminary experiments. Figure 1 shows input 32 images acquired with a gaze observation and estimated camera positions. Figure 2 show input 9 images and estimated camera positions. Figure 3 and Figure 4 show point clouds generated in our preliminary experiments. The results in our experiments, point clouds from 9 images were generated as well as that from 32 images. Thus, this result indicates that we could reduce the number of images to improve the efficiency in image acquisition and 3D modeling. However, when we focus on the stability and accuracy in SfM processing, an overlap rate should be evaluated. The overlap rate can be managed based on planer arrangement of images in conventional aerial Photogrammetry and SfM. On the other hand, the overlap rate management would be complicated in gaze observation. Gaze observation is an approach to acquire data for all aspects of an object from various points using a camera that is mounted on a moving object such as unmanned aerial vehicles (UAV). Although the efficiency in image acquisition depends on the complexity of object, gaze observation is also an effective approach for 3D environmental data acquisition in a dense local area. Efficient image acquisition would improve a time for UAV operation and image acquisition using handheld camera. Thus, we propose and evaluate camera path designs to improve the efficiency in image acquisition. In particular, we focus on ground-based image acquisition for SfM and 3D modeling.

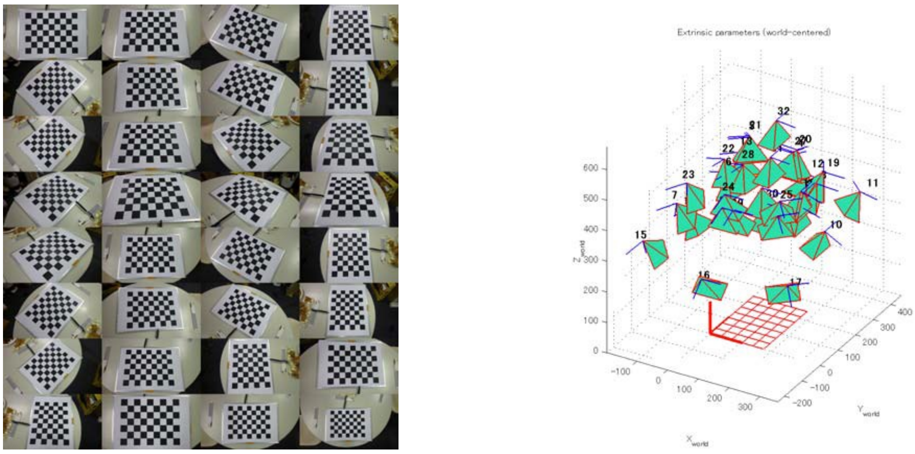

Figure 1. Result in our preliminary experiment (1)
(left image: input images, right image: estimated camera positions)

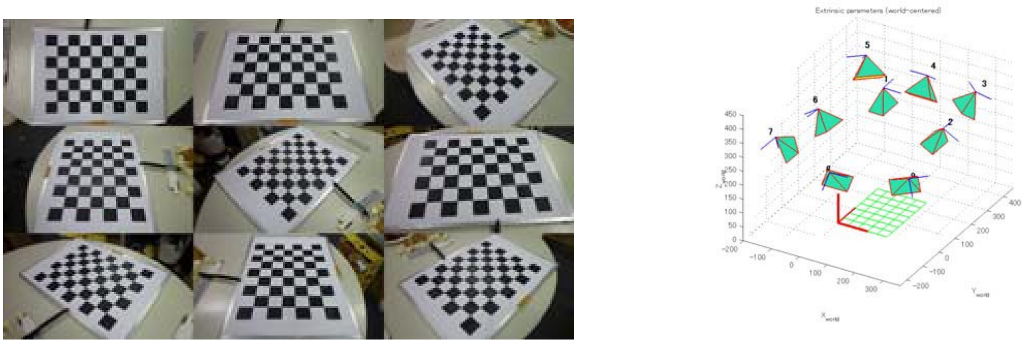

Figure 2. Result in our preliminary experiment (2)
(left image: input images, right image: estimated camera positions)

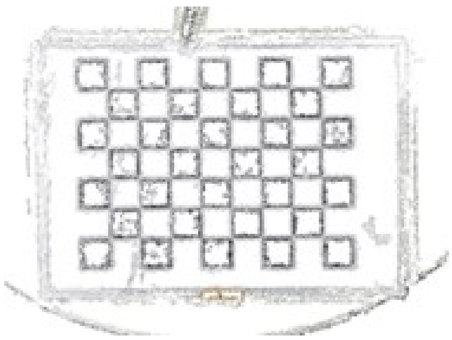

Figure 3. 3D modeling result using 32 images

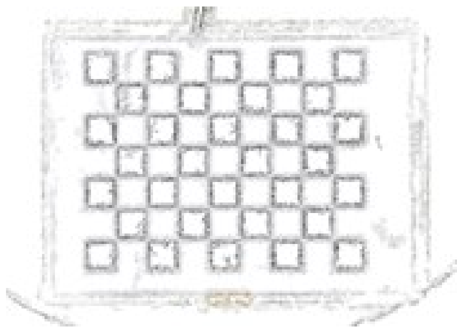

Figure 4. 3D modeling result using 9 images

2. METHODOLOGY

Figure 5 shows an example of an image acquisition route made for ground-based building measurement. In the ground-based measurement, images would be captured along the building walls to keep the same distances from a camera to the measured object to manage the spatial resolution in 3D modeling after the SfM processing. Moreover, there are several parameters, such as the overlap rate, side lap rate, viewing directions and viewing angle, to evaluate the efficiency in image acquisition. Thus, in this paper, we focus on camera positions and the number of input images to evaluate the efficiency in the image acquisition, using the following equation.

$$\text{Captured range} = \text{Distance from a camera to object} \times \text{Image sensor size} / \text{Focal length} \quad (1)$$

Additionally, images should be acquired at the corner parts of objects, because the corresponding points are less than other parts to generate point clouds. Finally, we evaluate the efficiency, based on processing time, the number of shots input images, the number of point clouds, and point cloud density.

Figure 5. Image acquisition route for ground-based building measurement

2.1 Structure from Motion (SfM)

Structure from Motion (SfM) is often applied to generate 3D data. Figure 6 shows an example in our preliminary experiment. The SfM is point-based matching and 3D modeling using corresponded points estimated with Scale-Invariant Feature Transform (SIFT). The SfM is useful approach to generate 3D data from images of random viewpoints. However, the SIFT requires a plenty of time to detect feature points and corresponded points from multi-images.

Figure 6. SfM processing using images from a UAV

2.2 Camera path design

We proposed a camera path design to acquire point cloud effectively. The following two points are assumed to be an ideal camera path. First, point clouds are generated with the minimum number of images. Thus, overlap and sidelap rate would be minimum to reconstruct point cloud. Second, no missing areas exist in image acquisition. We evaluate an efficiency improvement with an increase in the number of point cloud, increase in point clouds density, and reduction in an overall processing.

3. EXPERIMENTS AND RESULTS

We used a GPS camera (EXILIM Hi-ZOOM EX-H20G, CASIO) in this our experiment experiments. Our experiments consisted of three observations, such as a panoramic observation, translation observation, and, gaze observation. Moreover, we conducted two types of image acquisitions. In the first image acquisition, students without knowledge of Photogrammetry acquired images for the SfM. In the second image acquisition, images were acquired based on our camera path design.

Focal length	4.3~43mm
Image size	4320x3240 pixel
Image sensor	1 / 2.3-inch square pixel CCD

Figure 7. EXILIM Hi-ZOOM EX-H20G

3.1 EXPERIMENT-1

Figure 8 shows measured object and input 101 images. A signboard was selected as the measured object to evaluate our camera path design for plane objects. Figure 9 shows point clouds generated using the input images. Although point clouds were not generated from homogeneous black areas, many colored features were reconstructed successfully. Moreover, the center of the signboard was reconstructed because of a well-overlapped area.

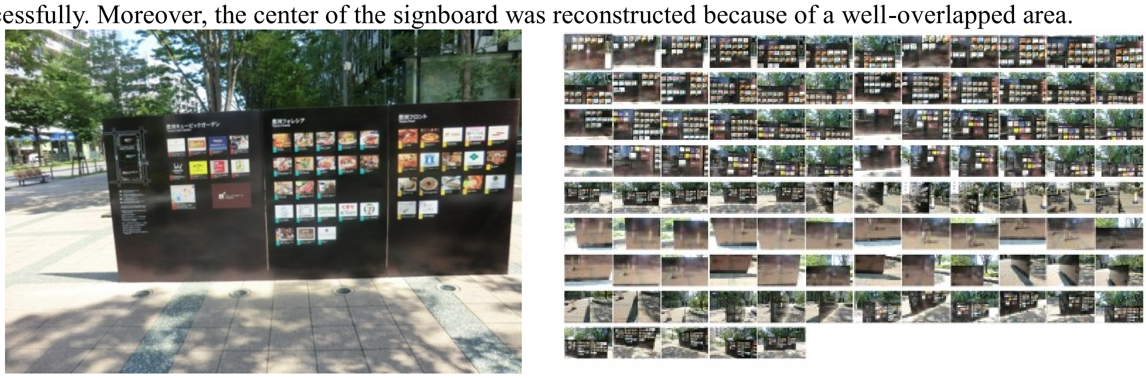

Figure 8. Result in experiment (1)
(left image: measured object, right image: input 101 images)

Figure 9. Generated point cloud of the signboard

3.2 EXPERIMENT-2

Figure 10 shows measured object and input 82 images. We have acquires the image at 90% overlap rate and 70% sidelap with our camera path, as shown in Figure 11. Figure 12 shows point cloud data generated using acquired images in this experiment. Although dense point clouds were obtained, some parts were sparse because ivy existed on the walls.

Figure 10. Result in experiment (3)
(left image: measured object, right image: input 82 images)

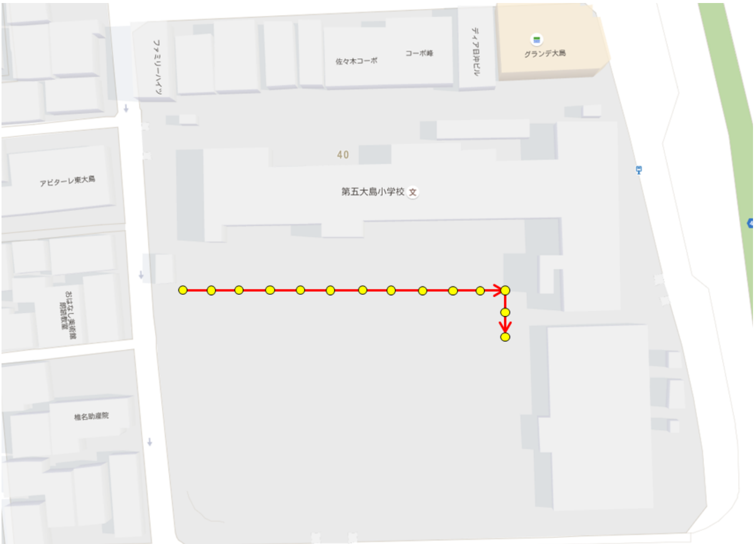

Figure 11. Camera path design of in our experiment (3)

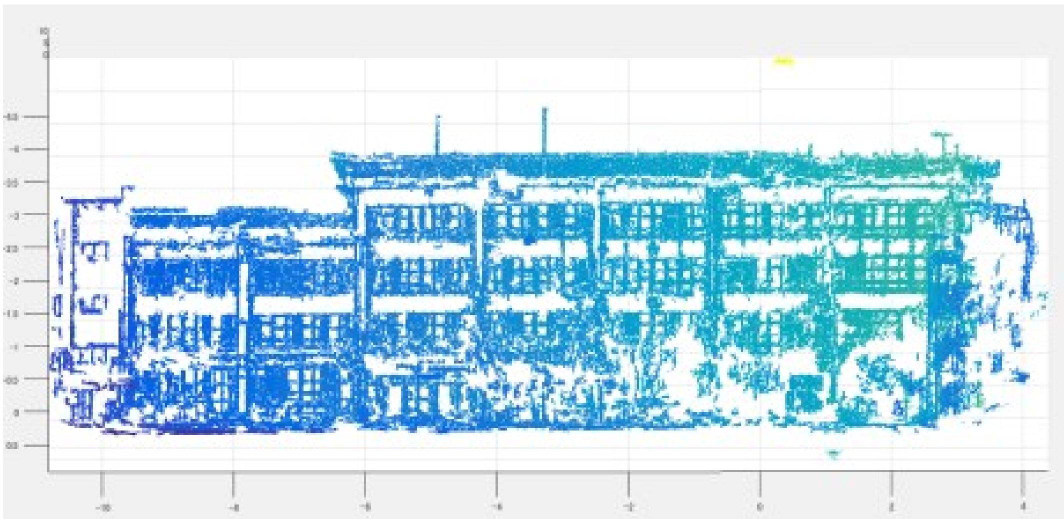

Figure 12. Generated point cloud in experiment (3)

3.3 EXPERIMENT-3

Figure 13 shows measured object and input 180 images. A bronze statue was selected as the measure object to evaluate our camera path design for block object. Figure 14 shows point clouds generated using the input images. Although point cloud were generated successfully, it approximately took two hours to find the corresponding points, because many feature points were extracted in images.

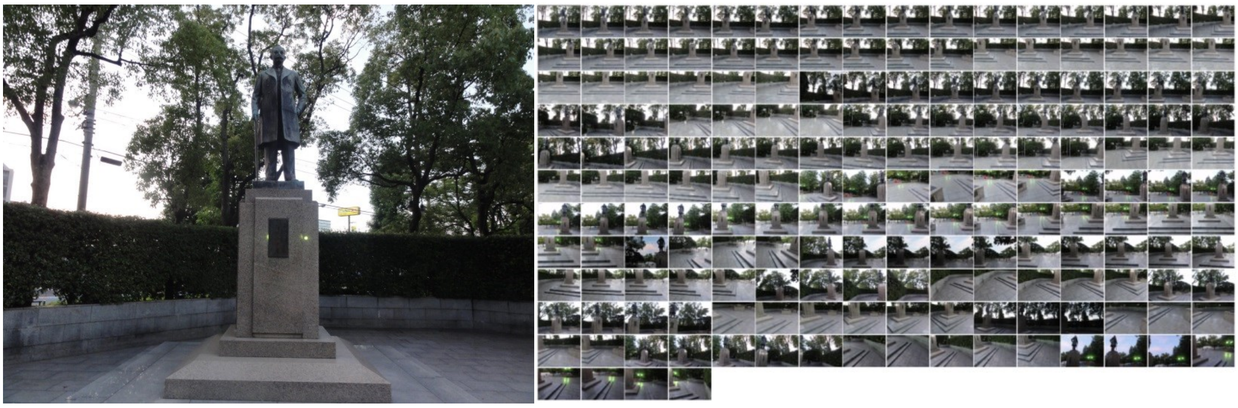

Figure 13. Result in experiment (2)
(left image: measured object, right image: input 180 images)

Figure 14. Generated point cloud of a bronze statue

We summarized our results in our experiments in Table 1. Also, it should acquire densely because point cloud became sparse.

Table 1. Summarized the acquired data

	Processing time [h]	The number of images	The number of point cloud [pts]
Experiment 1	1.34	101	638,638
Experiment 2	1.56	82	914,055
Experiment 3	3.2	180	2,322,880

4. DISCUSSION

In our experiments, we prepared beginners and educated beginners in image acquisition works. The beginners were students without knowledge of the SfM. After image acquisition works, the beginners had short lectures related to the SfM to acquire images from better camera positions. Then, we compared results using images taken by beginners with results using images taken by educated beginners.

We lectured on image acquisition for students. Main content in our lecture was to keep 90% overlaps in the image acquisition for 3D reconstruction. However, there were two main technical issues. The first issue was obstacles, such as pedestrian and trees in front of objects. The second issue was brightness changes during image acquisition. These issues caused mismatching in point cloud generation. Thus, lectures related to these issues would be included within knowledge of SfM processing.

In our experiments, we created a camera path design based on camera positions and the overlap rate. However, the number of corresponding points was not enough to reconstruct whole environments. Therefore, the overlap rate would be improved. Moreover, image acquisition environment, such as image acquisition time and weather condition, would be discussed to process the image matching. For example, in our experiments, changed shadowed area caused mismatching in image matching for SfM processing.

In our future works, we would manage images with several blocks to improve the accuracy in image matching. In addition, we would create a camera path with obstacle information.

5. CONCLUSION

We focused on a camera path design to improve the efficiency of SfM with ground-based gaze observation. In our research, we have found that there were several technical issues in image acquisition works for SfM processing. Therefore, we proposed a camera path design to assist a ground-based image acquisition. In our future works, we would add more parameters, such as spatial image resolution, a distance from a camera to objects, mobility area, and illumination changes.

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