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Study of Using Sum to Improve Digital Archives Integrity of Traditional Architectures with 3D Laser Scanning Technology

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Abstract: *3D laser scanning technology has been widely applied to digital archive and management of historical buildings, and that is enormous contributions for human civilization inherited. But the technology is limited by complex structure of scanned object or shaded of spatial pattern, and some important and pivotal 3D digital mode will be lost, and resulting in subsequent applied problems. In this study, try to obtain miss 3D point cloud by 3D laser scanning using SfM, and reintegrate to the original 3D point cloud model for insufficiency of 3D laser scanning technology. Get the relationships of photo distance, number of photos and deviation of 3D point cloud mode through the targets are uniformly scattered in a square wall with the area of 1.80m×1.20m. The research results show that the objects can obtain the 3D point cloud mode through the combination of the use of SfM technology at 7m in distance with more than 6 images, and when the 3D point cloud mode obtained through Ground Lidar with scan distance between 5m to 7m, the error is 0.005m~0.006m, which has been confirmed in the actual case. That is to say, the concordance of Lidar and SfM will be beneficial to the integrity and application of the 3D point cloud model of the historical architectures.*

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I. Introduction

Historical buildings which recorded the ancient science and technology, architecture, art and culture etc. were built by the ancestors in order to survive and adapt to the environment. Every ancient building can tell a glorious story, and it inherited the culture and technology of mankind, and witnessed the lifestyle, cultural modes and civilization of the people at that time. But after hundreds, or even thousands of years of weathering and man-made destruction, many monuments have been seriously damaged, and some even have collapsed or been completely destroyed. Many historical buildings in the world are facing extinction, therefore, it is very important to preserve and restore the monuments to make the cultural heritage of mankind be sustained. We should try to get the correct mode with high precision for the subsequent preservation and repair work, for instance, after the successful repair of historical monuments such as the Parthenon in Greek [1] and the Mengjia Longshan Temple in Taiwan [2], these buildings can be visited by our descendants, and continue to witness the human civilization and inherit the historical culture.

Today, the 3D point cloud mode obtained by Ground Lidar is mainly used to measure the spatial dimensions of historic buildings, and its measurement accuracy can be accurate to centimeters [3]. Due to the overcomplicated structures of some buildings, the point cloud data of key dimensions cannot be obtained, leading to the need for manual mapping; while the results got from manual mapping are less accurate than the sizes got from the mapping of point cloud data, thus violating the spirit of eliminating human error through surveying and mapping automation. Therefore, this study tries to integrate the technologies of SfM [4] and Ground Lidar, in order to obtain more complete data and more accurate mapping results, thus leading to more perfect work of preservation and restoration of historic buildings.

In order to improve the mapping accuracy used for the preservation and restoration of historical buildings, the technologies of SfM and Ground Lidar must be integrated, and the point cloud got from SfM technology should be combined with that got from Ground Lidar to obtain a more complete mode for reducing human error. In addition, many complex components cannot get the complete point cloud data due to the overly complex position, angle or structure, so the field observation or photographs combined with manual mapping are needed to complete the surveying and mapping work.

When the complex structures and building corners are presented with SfM technology, and the point cloud data are measured by the scan of Ground Lidar, the efficiency of scan operations will be improved, and the artificial mapping will be reduced, thus achieving the purpose of eliminating human error through surveying and mapping automation.

II. Research Content

The two main techniques applied in this study were Ground Lidar and SfM. In this paper, in addition to the the theories of the two technologies, I will also introduce the research method designed for achieving the research objective, including the analysis on the difference quantity of the corresponding distance of 3D point cloud mode based on SfM technology and Ground Lidar technology at different distances from the scanned objects. The real case, “the component composition of the foreyard of Wang Jincheng Mansion of Kinmen” was test, in order to discuss the usability of the integration of SfM and Ground Lidar in a practical case.

II-1. Ground Lidar

The Ground Lidar Principle can be classified as contact and non-contact, and the latter can be classified as active and passive scan. In 1960, the first ruby laser in the world was invented by Maiman [5], which has been widely used in medicine, military, industry, construction and other fields. Ground Lidar adopts the non-contacting passive scan. The laser beams emitted by the origin from the laser can be divided into solid-state lasers and gas lasers in accordance with the different laser materials, and ranging principles can be divided into time difference principle and phase difference principle, thus calculating the relative coordinate of the measuring point and the origin. The data obtained are the three-dimensional coordinates of the measured point (X, Y, Z) and the laser reflected intensity (I). The basic principle of laser ranging is that the distance between the laser emission center and the reflection point can be obtained by the time or phase difference of transmitting and receiving the reflected light from the object of laser [6]. The Ground Lidar in this study used the phase laser ranging principle, that is, using the phase difference between the reflected light and the reference wave got from laser irradiation to measure the distance D of the object to be measured. When the lasers are shot towards the objects at the other end of the measuring line, signals from the reflection will be received by the receiver, and the phase comparison between transmit signals and received signals will be conducted by a phase meter, thus the phase difference $\Delta\varphi$ produced from the round-trip transmission of laser lights at the measuring line can be obtained. The distance represented by the phase difference can be calculated according to the wavelength of laser light. The equation is shown in (Eq. 1), and the principle is shown in Figure 1 [7].

$$D = \frac{1}{2}(N\lambda + \Delta\lambda) = N\frac{\lambda}{2} + \frac{\Delta\varphi}{2\pi}\frac{\lambda}{2} \qquad \text{(Eq. 1)}$$

In the equation:
D: distance; N: wave number in integer; λ: wavelength; $\Delta\varphi$: phase difference

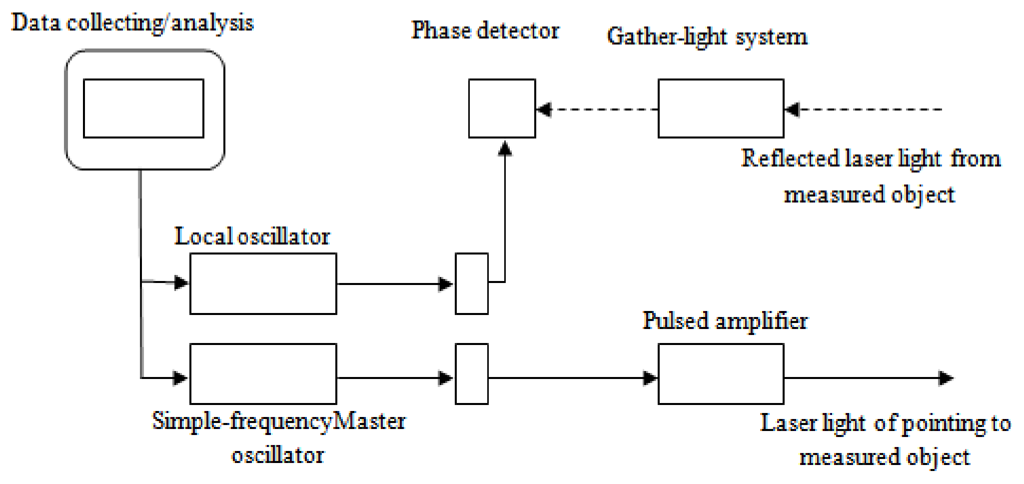

Figure 1. Phase-based Laser Ranging Principle [7]

II-2. Structure from Motion (SfM)

SfM technology has been proposed since 1979 [8] and has not been applied until 2000 [9]. The application scope of SfM is very wide, from many sub fields of the Geological Sciences (tectonics, geomorphology, structural geology, geodesy, mineralogy) to archaeology, architecture and agriculture. In addition to orthorectify image, SfM technology can also produce 3D cloud point model, and integrate the application of derivative and lidar system. And 3D processing combines scale-invariant feature transformation, or SIFT and SfM for the algorithm to become commercial 3D processing software. The relevant technology application processes are as follows:

- Using SIFT to detect conjugate feature points
- Matching the conjugate feature point
- Camera position, azimuth and distortion calculation and adjustment
- Using SfM for 3D cloud point reconstruction
- Reconstructing 3D surface with Triangulated Irregular Network (TIN)
- Attaching object texture (image)

II-3. The Experimental Process

The objective of the experimental design is to respectively use Ground Lidar and SfM technology for the same target to obtain their respective 3D point cloud modes, and the factor that affects the Ground Lidar is the scan distance. The longer the scan distance is, the bigger the scan error will be, so there are experimental designs with different scan distances. In addition to the shooting distance, the factors that affect SfM results also include the number of pictures, the overlap rate of adjacent images and so on, which will all cause inconsistent accuracies, so there are experimental designs with different shooting distance and different numbers of images. Finally, the distance between the same position of 3D point cloud modes obtained by the two technologies will be measured and the difference quantities in the vertical, horizontal and diagonal directions will be analyzed, in order to learn that what the accuracies of the results got from the 3D point cloud modes of SfM technology with different distances and image numbers integrateing with the 3D point cloud mode of Ground Lidar are. The experiment results can be used as important reference information of data acquisition in field operation.

II-3-1. The Design of Experimental Site

First, 35 targets in rectangular distribution were placed on a wall (Figure 2, left), and the locating place and the camera position of the Ground Lidar scanner were respectively set up at 5m and 7m from the center. In order to ensure the instrument center and the camera center are perpendicular to the target center in rectangular distribution when scanning and photographing (Figure 2, left, in the red circle), the theodolite was used in the experiment to place them in the same horizontal line (Figure 2, right). And when using SfM to set up the objects of 3D point cloud mode, the adjacent overlap images would be needed, therefore, outside the vertical direction, about 15∘ and 20∘ to the center from the right and left were set as the camera position (Figure 3). The camera captured 3 adjacent overlap images at 5m and 7m; the other 6 adjacent overlap images were captured for a high degree of overlap. The following research projects include:

- At 5m and 7m form the center, Ground Lidar was respectively analyzed with the difference quantities measured by SfM with 5m (3 images), 5m (6 images), 7m (3 images) and 7m (6 images)
- Global difference quantities were analyzed based on the best combination of precision

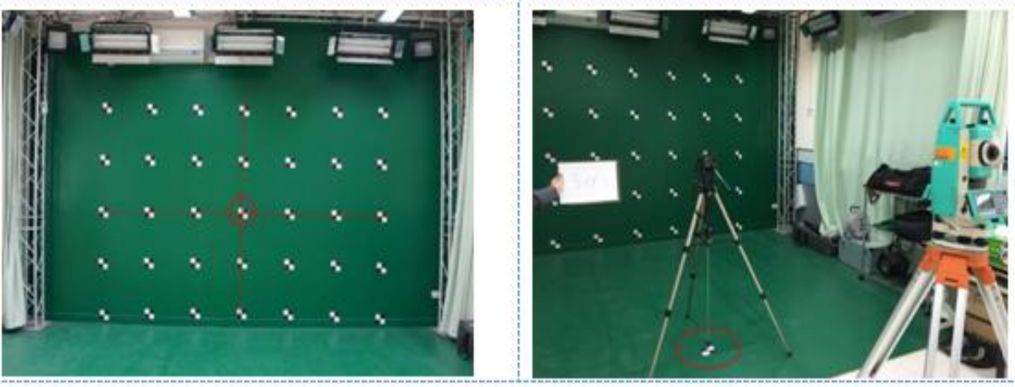

Figure 2. The targets in rectangular distribution (left);using theodolite to control at the same level (right)

II-3-2. The Measuring Method of Data

First the targets were numbered from left to right and top to bottom in No. 01~35, and the center target was No. 18. The 3D point cloud modes were obtained by Ground Lidar and SfM, and distances between the targets in the same number were respectively measured based on No. 18 target to the horizontal direction, vertical direction and diagonal direction, then the follow-up difference quantities were analyzed.

III. Result Analysis and Case Discussion

After completing the measurement and recording the relevant data according to the experimental design process, data from the above analysis projects can be obtained (Tables 1 and 2). It is shown in Table 1 that the difference quantity is the absolute value of 3D point cloud modes obtained through Ground Lidar and SfM, and when the Ground Lidar was at 7m, 6 images at 7m were taken and the difference quantity measured by 3D point cloud modes obtained by SfM was the best, 0.0053m. In addition, it is showed in Table 2 that, when the Ground Lidar was at 5m, 6 images at 7m were taken, the difference quantity measured by 3D point cloud modes obtained by SfM is the best, 0.0051m. so we learn from Tables 1 and 2 that, whether the Ground Lidar was at 5m or 7m with 6 images at 7m, the difference quantities measured by 3D point cloud modes obtained by SfM are the best, between 0.0051m~0.0053m. Now take the combination in the minimum difference quantity as an example, and conduct the measurement in accordance with the following steps:

- Horizontal direction: 18 ->17->16->15, 18->19->20->21
- Vertical direction: 18->11->4, 18->25->32
- Oblique direction: 18->9, 18->1, 18->23, 18->29, 18->13, 18->7, 18->27, 18->35

The measurement results are shown in Table 3. The average errors of horizontal direction, verticaldirection and oblique direction are 0.0044m, 0.0062m, and 0.0068 respectively, and the overall average difference is 0.0057m. Therefore, if we integrate the combination applications of 3D point cloud mode from Ground lidar and SfM, and get the 3D point cloud mode from Ground Lidar at 5m or 7m, for the location cannot be scanned (such as the target distribution in 0.18m x 0.12M), the Ground Lidar can be placed at 7m with 6 images, and the 3D point cloud mode can be obtained by SfM, so the range of error should be below 0.006m. If taking the error analysis according to the areas of scanned objects, it is showed in Table 4 that the mean difference quantities based on different area of 0.60m x 0.60m, 1.20m x 1.20m and 1.80m x 1.20m are 0.0056m, 0.0058m and 0.0056m respectively, so the mean difference quantities within the range of the above sizes are quite close.

Table 1 The Difference Quantities Measured by 3D Point Cloud Modes through Ground Lidar and SfM (1)

Direction	Distance (number)	Ground Lidar (5m)		Ground Lidar (7m)	
		5m (3 images)	5m (6 images)	7m (3 images)	7m (6 images)
Horizontal Direction	18-19	0.0002m	0.0057m	0.0003m	0.0032m
	18-20	0.0096m	0.0130m	0.0061m	0.0031m
	18-21	0.0125m	0.0190m	0.0050m	0.0088m
Vertical Direction	18-11	0.0049m	0.0018m	0.0037m	0.0089m
	18-04	0.0105m	0.0065m	0.0195m	0.0123m
Oblique Direction	18-13	0.0057m	0.0121m	0.0169m	0.0010m
	18-07	0.0115m	0.0163m	0.0207m	0.0003m
Mean Difference Quantities		0.0079m	0.0106m	0.0089m	0.0053m

Note: difference quantities =|Ground Lidar─SfM|

Table 2 The Difference Quantities Measured by 3D Point Cloud Modes through Ground Lidar and SfM (2)

Direction	Distance (number)	Ground Lidar (5m)		Ground Lidar (7m)	
		7m (3 images)	7m (6 images)	5m (3 images)	5m (6 images)
Horizontal Direction	18-19	0.0000m	0.0029m	0.0003m	0.0060m
	18-20	0.0060m	0.0030m	0.0097m	0.0131m
	18-21	0.0063m	0.0075m	0.0138m	0.0203m
Vertical Direction	18-11	0.0041m	0.0093m	0.0045m	0.0014m
	18-04	0.0197m	0.0125m	0.0103m	0.0063m
Oblique Direction	18-13	0.0166m	0.0007m	0.0060m	0.0124m
	18-07	0.0209m	0.0001m	0.0113m	0.0161m
Mean Difference Quantities		0.0105m	0.0051m	0.0080m	0.0108m

Note: difference quantities =|Ground Lidar─SfM|

Table 3 The Difference Quantities Measured by 3D Point Cloud Modes through Ground Lidar and SfM (3)

Direction	Distance (number)	Ground Lidar (5m)
		7m (6 images)
Horizontal Direction	18-19	0.0029m
	18-20	0.0030m
	18-21	0.0075m
	18-17	0.0050m
	18-16	0.0024m
	18-15	0.0057m
The Average Error in Horizontal Direction		**0.0044m**
Vertical Direction	18-11	0.0093m
	18-04	0.0105m
	18-25	0.0055m

	18-32	0.0000m
The Average Error in Vertical Direction		**0.0062m**
Oblique Direction	18-13	0.0007m
	18-07	0.0001m
	18-27	0.0125m
	18-35	─
	18-23	0.0138m
	18-29	0.0074m
	18-09	0.0002m
	18-11	0.0093m
The Average Error in Oblique Direction		**0.0063m**
The Overall Mean Difference		**0.0057m**

Note: difference quantities =|Ground Lidar─SfM|

Table 4 The Average Error in Areas of Different Digital Ranges

The Areaswere Scanned (m^2)	The Distances Between Targets	Mean Difference Quantities
0.60m×0.60m	18-11,18-19, 18-25, 18-17	0.0056m
1.20m×1.20m	18-11, 18-19, 18-25, 18-17, 18-04, 18-13, 18-20, 18-27, 18-32, 18-23, 18-15, 18-09	0.0058m
1.80m×1.20m	18-11, 18-19, 18-25, 18-17, 18-04, 18-13, 18-20, 18-27, 18-32, 18-23, 18-16, 18-09, 18-07, 18-21, 18-35, 18-29, 18-15, 18-01	0.0056m

Note: difference quantities =|Ground Lidar─SfM|

IV. Case Analysis

This research took the digitizing 3D scan of the foreyard of Wang Jincheng Mansion of Kinmen as a case. The 3D point cloud mode of the foreyard was obtained through the scanning of Ground Lidar first (Figure 4, left), but due to the shielding, the data of some structures could not be got. Because those structures have cultural value, thus by was obtained through SfM technology and then combined with the 3D point cloud got through ground Lidar, thus obtaining the complete 3D point cloud mode. After the completion of relevant procedures and data processing according to the experiment content of this study, the complete combination of 3D point cloud mode can be obtained using FARO SCENE(Figure 4, right), and the combination error is ± 0.0051m (Figure 5), which is consistent with the experimental result of this study, and the accuracy is also in line with the combination error limitation (<0.010m) of 3D point cloud mode of traditional architecture scanned by Ground Lidar in Taiwan [10].

Figure 4 The 3D point cloud mode of the foreyard of this building scanned by Ground Lidar (left);the 3D point cloud mode after combination (right)

参考	距...	角...	扫描 1	扫描 2
Sphere10	6.23	---	20151120008	20151120015
Sphere10	7.03	---	20151120008	20151120012
Sphere10	8.68	---	20151120008	20151120010
Point9	14.46	---	20151120005	123T
Point8	7.29	---	20151120005	123T
Point7	6.95	---	20151120005	123T
Point6	10.95	---	20151120005	123T
Point5	8.40	---	20151120005	123T
Point4	14.10	---	20151120005	123T
Point3	21.19	---	20151120005	123T
Point22	9.97	---	20151120005	123T
Point21	11.49	---	20151120005	123T

距离/角度统计

平均： 5.12 [mm] 0.000 [°]

最小： 0.64 [mm] 0.000 [°]

Figure 5 The Combined Error of 3D Point Cloud Modes Got from Ground Lidar and SfM(by FARO SCENE)

V. Conclusion

In Taiwan, Ground Lidar is widely used as an important tool in the digitization of traditional architecture, and the obtained 3D point cloud mode is helpful to the follow-up survey, damage survey, navigation and other applications. While the shield often causes the decoration, construction and cultural relics with cultural value cannot be scanned in digitization, and even damages 3D point cloud mode, which is bad for subsequent applications. This study used SfM technology to make up for the covered objects and adopted a flexible method of photography to obtain the overlap image data, constituting the 3D point cloud mode of the place that cannot be measured, and combined both the 3D point cloud modes through the datum transformation. The research results show that the objects in the area range of 1.80m x 1.20 can obtain the 3D point cloud mode through the combination of the use of SfM technology at 7m in distance with more than 6 images, and when the 3D point cloud mode obtained through Ground Lidar with scan distance between 5m to 7m, the error is 0.005m~0.006m, which has been confirmed in the actual case. Therefore, the integration of Ground Lidar and SfM will be helpful to the digital integrity of traditional architecture, and will provide more information sources for the applications of Building Information Modeling (BIM) in the future.

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