Establish A 3-D Model Using Laser Scanner At A Fixed Station

Hao-Hsiung Huang
Associate Professor, Department of Land Economics
National Chengchi University
64, Sec.2, ZhiNan Rd., Wenshan, Taipei, 11605, China Taipei
hhh@nccu.edu.tw

Wei-Kai Fang
Graduate Student, National Chengchi University
64, Sec.2, ZhiNan Rd., Wenshan, Taipei, 11605, China Taipei
93257018@nccu.edu.tw

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ABSTRACT: To establish a 3-D model without moving laser scanner has been the primary motivation of this study. Compared with traditional ground surveying instruments, laser scanner can be used to collect object's spatial information in an efficient way. However, when using a laser scanner, it still needs multi-viewpoint way to establish the 3-D model completely. In general, the laser scanner has to be set up at more than two stations, and the data scanned by different viewpoint should be joined together to complete the scan work.
On the other hand, assume that an object can be rotated, its different part can be scanned using a laser scanner set up only one time. The scanned data can be joined together and generated a 3-D model of the object by using three dimensional conformal coordinate transformations. The whole procedure will be explained in this paper. Results generated from scanning at only one station will also be compared and analyzed.

1. Introduction

The most significant difference between ground-based and airborne LiDAR is that the ground-based LiDAR needs to be fixed on the ground when scanning. To complete a scan of any stationary object, the operator has to move the scanner several times at different viewpoints since LiDAR can only acquire data from the visible side of the object.

In reality however, the ground-based LiDAR may weighs 17kg and for an average person to set and reset over different viewpoints requires careful handling, time to reset, and laborious work. If the object to be scanned covers a mass area such as a building, the operator would have no choice but to move the LiDAR around the building to acquire all the possible viewpoint of the building. But, if the object can change its orientation at one site instead of moving the LiDAR, would it be more labor saving while acquiring the same efficiency? In this study, an experiment was conducted by changing the orientation on a remote-controlled helicopter while the ground-based LiDAR stay in the same orientation during an on going scanning operation.

2. Experiment theory

When scanning with LiDAR, there are two procedures to be done to create useful data.
Firstly, determine the viewpoint. To acquire enough points to form an object model, LiDAR has to scan at least two different viewpoints. The exact number of viewpoints is determined on the shape and size of the object to be scanned. More complex shapes require more viewpoints to incorporate more surfaces while simple shapes require less. The number of viewpoints should be chosen adequately, since more data means more data processing and more accumulation of systematic errors.
Secondly, how to connect point from different viewpoints. To use the points acquired to form an actual model, there are two major methods that could be applied:

- Connect point to point: through Iterative Closest Point method (ICP) and find the smallest distance RMSE among two data
- Connect by feature: by extracting points, lines, and plane from the point clouds and match against each other. Connect by point feature is the most commonly used. It is done by setting target in adequate positions and search the adjacent points from scans to connect different data

ICP does not need target points. But, in order for ICP to achieve idea results, the two point clouds from two different viewpoint scans must have more similar points and often take longer time in post processing. Even though it take longer time to find ideal target in the second method, the post processing is just coordinate transform and accuracy check and is much faster than the first.

2.1 Three-dimensional conformal coordinate transformation

In theory, the Z-axis in the point cloud's coordinate system is perpendicular to the earth surface. But, take account of the error in tilt and earth's curvature, Z-axes in any two set of point clouds would not likely be parallel to each other. To correct this, a 3D conformal coordinate transformation is applied to calculate the parameter of ($S, \omega, \phi, \kappa, T_x, T_y, T_z$).

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = S \begin{bmatrix} m_{11} & m_{21} & m_{31} \\ m_{12} & m_{22} & m_{23} \\ m_{13} & m_{23} & m_{33} \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} + \begin{bmatrix} T_x \\ T_y \\ T_z \end{bmatrix}$$

$$m_{11} = \cos\phi\cos\kappa$$
$$m_{12} = \sin\omega\sin\phi\cos\kappa + \cos\omega\sin\kappa$$
$$m_{13} = -\cos\omega\sin\phi\cos\kappa + \sin\omega\sin\kappa$$
$$m_{21} = -\cos\phi\sin\kappa$$
$$m_{22} = -\sin\omega\sin\phi\sin\kappa + \cos\omega\cos\kappa$$
$$m_{23} = \cos\omega\sin\phi\sin\kappa + \sin\omega\cos\kappa$$
$$m_{31} = \sin\phi$$
$$m_{32} = -\sin\omega\cos\phi$$
$$m_{33} = \cos\omega\cos\phi$$

2.2 Examine accuracy

But after the initial processing, the coordinate system is still in free coordinate system. Therefore, for the data to be available for analyzing, the coordinate system from the scans are required to be transformed to ground coordinate system and then re-measure and re-calculate the target to compute the RMSE accuracy.

3. Experiment design

The objective of this experiment is to scan a remote-controlled helicopter with the Leica HDS3000 LiDAR and recreate a 3D model using post processing software “Cyclone 5.4”. When scanning, the size of the target and the object surface are taken into account as physical limitations. The target size is predefined to 7.5cm in diameter and because of it size can not be placed anywhere onto the helicopter itself due to the lack of flat surfaces.

The helicopter is first mounted on a rectangular box. The targets are placed on all sides of the rectangular box and none on the helicopter. During the scanning operation, LiDAR will scan the helicopter and the rectangle box as one solid entity. After the operation, all point-cloud data have be merged and processed to remove any part of the point cloud data that does not resemble the helicopter. The entire operation took 4 scans on object. When scanning, the rectangular box was set so that one corn was facing the LiDAR, allowing LiDAR to scan in two sides of the helicopter and the box. Following figures represent the helicopter’s and rectangular box’s respective orientation.

Figure 1: S1’s viewpoint

Figure 2: S2’s viewpoint

Figure 3: S3’s viewpoint

Figure 4: S4’s viewpoint

4. Experiment result and analysis

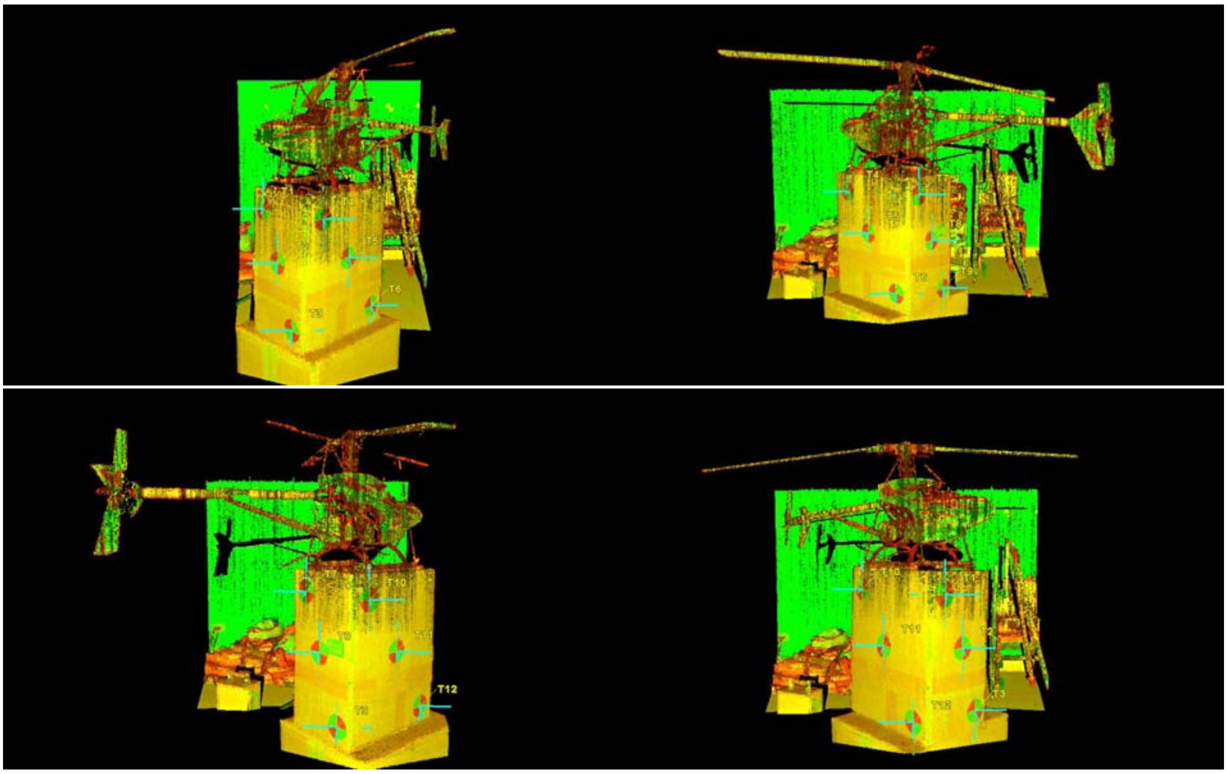

Figure 5: The helicopter's raw data from 4 viewpoint scans and the blue crosses represent the position of the control points.

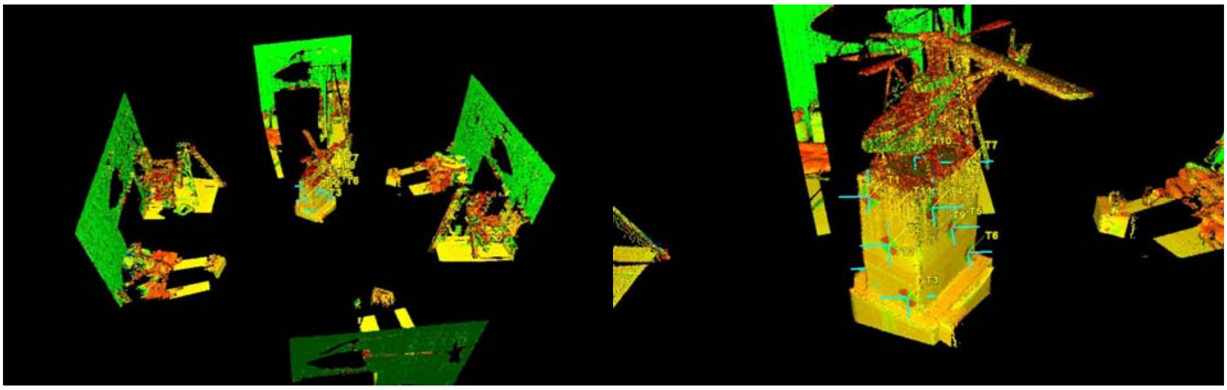

Figure 6: Represents the initial result in raw data from the 4 scans after coordinate transform.

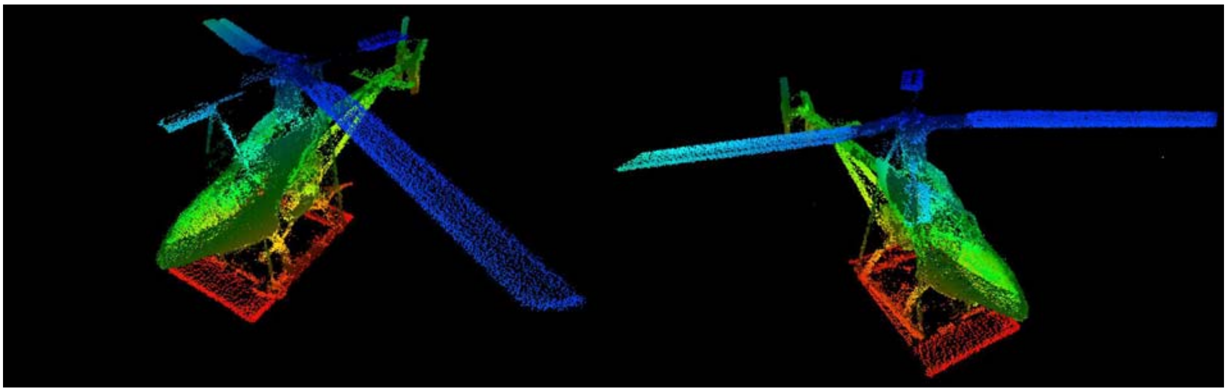

Figure 7: The result that is after deleting unnecessary data. The frame of the helicopter is formed and the every height value range is represented by different color.

5. Integrate accuracy analysis

The quality of the result object model is evaluated by the integrated accuracy among control points. Two transform methods were used and described as the following sections.

5.1 Transform method one

By using a total station and assuming that all coordinate is in ground coordinates system, all 12 control points are measured. Then, all the coordinate are changed into S1 coordinate system and divided into two groups. T1 to T6 coordinate are used for coordinate transform while T7 to T12 are used to examine coordinate differences. The result is display below:

Table 1: Twelve control points transform to S1' coordinate system (Unit: m)

TargetID	X	Y	Z	RMSE
T7	-0.0032	-0.0098	-0.0060	0.0120
T8	0.0045	-0.0082	-0.0050	0.0106
T9	0.0133	-0.0077	-0.0034	0.0157
T10	-0.0090	-0.0134	0.0040	0.0166
T11	0.0051	-0.0197	0.0092	0.0223
T12	0.0213	-0.0244	0.0127	0.0348

The RMSE is set to the range of 5mm and in this range shows a steady accuracy. When comparing X, Y, Z, Y's proportion in RMSE is larger than X and Z. According to the scanner's position, Y is related to distance while X and Z are related to horizontal and vertical angles. In the case where there is short distance and small angle, the affect on distance is always larger than angles which explain why Y's error is the larger in this experiment.

5.2 Transform method two

This method changes the coordinate system into the object coordinate system. Each scan has six control points, three for transform and others for accuracy. By using this method, it does not take into account of how to connect different scans, which reduces the number of times and error accumulation in post processing.

Table 2: Four scans transform respectively into object coordinate system (Unit: m)

SW	ID	X	Y	Z	RMSE	SW	ID	X	Y	Z	RMSE
S1	**T1**	0.0003	0.0003	-0.0003	0.0005	**S2**	**T7**	0.0003	0.0026	0.0024	0.0036
	T2	-0.0001	-0.0002	0.0001	0.0003		**T8**	-0.0004	0.0044	0.0012	0.0045
	T3	-0.0012	-0.0001	-0.0010	0.0016		**T9**	-0.0004	0.0035	0.0007	0.0036
S4	**T1**	0.0171	-0.0145	0.0008	0.0225	**S3**	**T7**	0.0009	-0.0021	0.0014	0.0027
	T2	0.0155	-0.0079	0.0046	0.0180		**T8**	0.0000	0.0007	-0.0002	0.0007
	T3	0.0105	0.0014	0.0068	0.0126		**T9**	-0.0007	0.0024	-0.0015	0.0029
S1	**T4**	0.0007	0.0010	-0.0004	0.0013	**S3**	**T10**	0.0027	0.0154	-0.0018	0.0158
	T5	0.0001	0.0015	0.0002	0.0015		**T11**	-0.0057	0.0145	-0.0040	0.0161
	T6	0.0004	0.0025	0.0004	0.0025		**T12**	-0.0164	0.0132	-0.0088	0.0229
S2	**T4**	-0.0511	0.0167	-0.0218	0.0580	**S4**	**T10**	-0.0013	0.0055	0.0002	0.0057
	T5	-0.0401	-0.0032	-0.0134	0.0424		**T11**	-0.0001	0.0055	0.0014	0.0057
	T6	-0.0253	-0.0257	-0.0038	0.0362		**T12**	-0.0008	0.0049	0.0008	0.0050

But in Table2, the size of RMSE is different than in Table1 and this result in different T1, T2, and T3 in both S1 and S4. This difference will cause the two point clouds to have a bad fit when merged together.

6. Conclusion and suggestion

Based upon the results, several conclusions and suggestions are drawn, as follows:

1. According to experiment result, scanning an object at a fixed location is feasible. And based on the integrate image and its accuracy; it has also achieved an acceptable accuracy.
2. Because of the equipment's limitations, the target needs a specific size when scanning targets to build control points. When choose scan object to scan, even though object's size isn't a factor, the location of the control points' position, and at least three points are needed for differentiate scans. For example, in this experiment, the helicopter isn't large enough to set targets. Therefore, it is mounted on other rectangular box where targets can be applied on.
3. The control points on any side of the rectangular surface must retain the same distance and angle between any other points of the same side. Otherwise it may cause bias when connect points and transform after each rotation.
4. Perhaps the most important factor of this experiment is control points. By improve the size or quality of the target, the accuracy could be increased accordingly. However, if the control point could be defined as a feature on the scanned object, then there would be more choices when choosing viewpoints.

7. References

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