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Development of ladder-type laser scanning system for 3-D modeling of vertical and narrow areas by space-time analysis

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Abstract

In this paper, we propose a novel type of 3-D scanning system named 'Ladder-type laser scanning system,' designed for scanning vertical and narrow areas. Two line scanners are equipped on a moving platform on a ladder, and scan through the whole target while the platform moves downwards along the ladder. One scanner (main) is for scanning the target, and the other scanner (sub) is for localizing the platform by using spatio-temporal range image. We can accurately calculate the speed of the moving platform, with which a correct 3-D model can be constructed from the main scanner. The system was used for modeling Bayon Temple in Cambodia as a part of our digital archiving project of cultural assets, and the scanning results proved that the system gives a sufficiently accurate 3-D model.

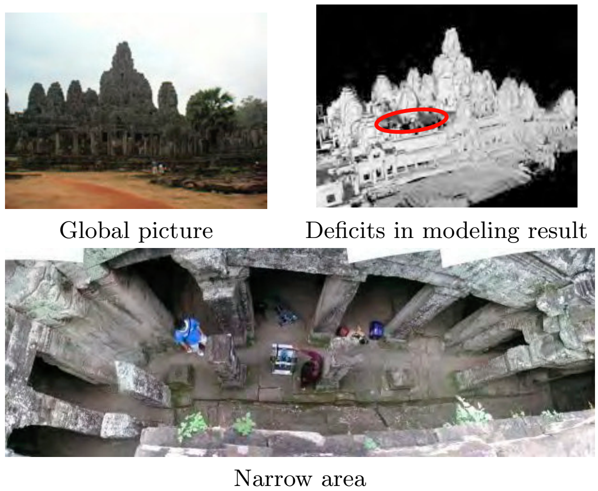

Figure 1: The Bayon Temple

1 Introduction

Modeling from reality – scanning an object in the real world and creating its 3D model – is one of the best-known topics in computer vision. One of its main application areas is for preserving valuable cultural assets [5][2][3]. Since such constructions deteriorate due to exposure to natural weathering and natural disasters, there's a strong need to guard and save them from further harm, and create an accurate model for restoration.

We have been scanning the whole geometry of the Bayon Temple in Angkor Thom (Fig. 1), using several commercial laser range scanners such as Cyrax 2500[4] and Z+F Imager[10], and some original ones. Although most of the Bayon has been modeled using them, there still remain quite a few deficits in narrow areas, as shown in the figure.

Such areas are hard or extremely inefficient to be scanned by ordinary commercial ones, due to their limitation of FOVs and the narrowness of the place to set them. Although Z+F Imager, which spherically scan the surroundings, can scan narrow areas without the FOV problem, it causes another problem that density of range points becomes extremely high or low from area to area. And moreover, the problem of distance ambiguity also occurs because of its scanning principle, phase-shift detection.

We developed a novel scanning system called 'Ladder-type laser scanning system,' or 'Climbing Sensor,' which enables to scan in such narrow areas with uniform range point density. It equips a moving platform with a laser range scanner on a lift, and scans through the whole target, while the platform moves upwards or downwards along a ladder.

2 System configuration

To quickly scan a target without enough space, we used a commercial lift equipped with a moving platform on a telescopic ladder, Nobitec Lift NP-4200[6]. And we arranged two, main and sub, LMS200 laser range scanner[7]

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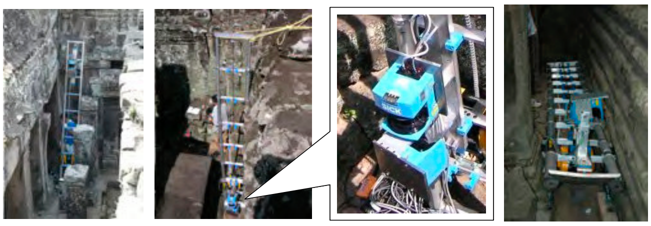


Figure 2: Overview of our system.

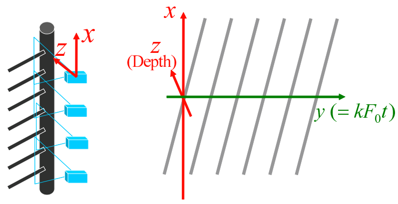


Figure 3: A basic notion of spatio-temporal range image.

on the platform, perpendicular to each other. The main scanner is placed horizontally to the moving direction of the platform, and the sub one is placed parallel to the moving direction.

The ladder is set against a wall, and the lift moves the platform upwards or downwards while two scanners are running. The main scanner can measure the whole object through the movement of the lift, and the sub scanner can be used to obtain temporal transition of the platform. An overview of the ladder-type laser scanning system is shown in Fig. 2. According to the spec sheet of NPL-4200, the moving speed is noted at 25m/min = 0.4167m/s. However, through our verification experiment, we found that the specified speed becomes inaccurate according to the scanning condition – since the lift is set against the wall, its inclination varies from case to case. Using the sub scanner, we will be able to attain more accurate speed of the movement.

The configuration described here solved the problem of the narrow space, horizontal FOV and uniform point density, since the small platform moves vertically along the lift with less space-consuming.

3 Localizing the platform

In this section, we describe how to localize the moving platform using the sub scanner. In order to avoid error accumulation, we propose to take advantage of space-time analysis of scanning result from the sub scanner, introducing spatio-temporal range image.

3.1 Spatio-temporal range image

Spatio-temporal range image is a kind of range image composed of a set of line-scanning range data. When a platform equipped with a line-scanner that moves to particular direction under condition that the moving trajectory is included in scanning planes of the scanner, overlaps between adjacent scanning frame inevitably occurs. Spatio-temporal range image can be acquired by placing these geometric scanning results next to each other along temporal axis, with constant intervals. In the case of our system, it can be acquired from the sub scanner as shown in Fig. 3.

Spatio-temporal range image has some interesting features. It simultaneously represents the spatial characters of the targeted scene, which can be represented as x in Fig. 3, and the temporal continuity of the movement, which can be represented as y. Additionally, range points in the spatio-temporal range image cluster and compose some planes in most cases, due to the overlap of scanning line and the difference of depth of the targeted scene from place to place. The second feature described above implies that it is easy to extract edges from spatio-temporal range image. By using the edge, the moving speed of the platform V can be calculated through the following equation

$$m = \frac{\Delta y}{\Delta x} = \frac{kF_0 \Delta t}{\Delta x} = \frac{kF_0}{V} \tag{1}$$

where m is a slope of the edge and x-y-z coordinate is defined as Fig.3, i.e. x is a scanning direction, z is a depth, O is a center of the laser source, F_0 is scanning rate of the sensor, and k is an interval between each scan in placing them next to each other along a temporal axis.

Through this approach, we can localize the moving platform with the accumulation of the error as small as possible since the approach contains no matching process for each frame. If we consider localizing the position of the platform directly without calculating the speed of motion, the necessity of a matching process for each frame arises which brings forth the error accumulation problem. With our method, the error can be dispersed throughout the whole process, therefore accurate models can be created.

3.2 Process overview

The outline of the algorithm is shown in Fig. 4. We can obtain spatio-temporal range image from the sub scanner. As seen in this figure, the edges of the range image can be distinguished easily.

3.2.1 Edge extraction

In order to extract edges from the range image, we used a Sobel filter and angular threshold.

The Sobel filter consists of two kernels that detect horizontal and vertical changes in an image. The filter is applied the Cartesian coordinates of the measured points, $\mathbf{c}_{m,n} = (x_{m,n}, y_{m,n}, z_{m,n})$, where m describes the

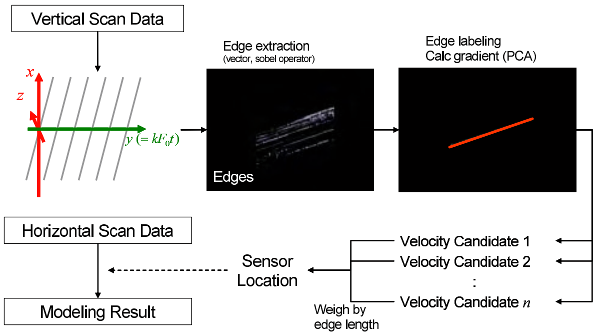


Figure 4: Outline of the localizing process.

scanning-line number and n describes the point in a specific scan. We applied the filter to $\mathbf{c}_{m,n}$ and 8 points around it: $\mathbf{c}_{m-1,n-1}, \mathbf{c}_{m-1,n} \cdots, \mathbf{c}_{m+1,n+1}$. Comparing the magnitude of the result with a threshold, we can extract edges.

Independent of Sobel filtering, angular threshold is also defined. We paid attention to two angles between the four points adjacent to $\mathbf{c}_{m,n}$:

$$angle_1 = \angle \mathbf{c}_{m,n+1}\ \mathbf{c}_{m,n}\ \mathbf{c}_{m,n-1} \tag{2}$$

$$angle_2 = \angle \mathbf{c}_{m+1,n}\ \mathbf{c}_{m,n}\ \mathbf{c}_{m-1,n} \tag{3}$$

If either of these two angles satisfy the following equation, we assumed the point to be an edge.

$$\frac{\pi}{12} < angle < \frac{11}{12}\pi \tag{4}$$

Finally, edge candidates which satisfy both of the conditions simultaneously is determined as edges.

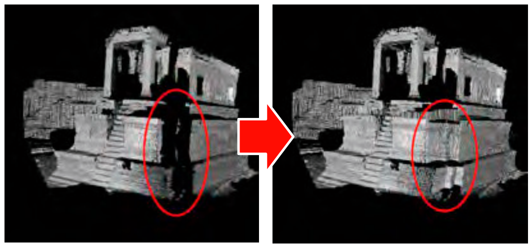
3.2.2 Calculating the speed of the moving platform

From the gradient of the edge, we can next calculate the speed of the moving platform. Here we assumed that the speed is constant considering the mechanism of the lift and the ladder – the platform is moved by an electric motor, where the load does not change in one sequential movement.

Multiple edges extracted from the previous description are labeled. and vector edge extraction, and PCA (principal component analysis) is applied to each edge for obtaining primary component, from which we derived the gradient of the edge.

Speed can be estimated from all edges. Each value is weighted each according to its length, and taken an average, which reflects that the longer the edge becomes, the more its error disperses, and the result will have higher reliability.

(a) Modeling result (Ex.1). (b) Actual scene.



(c) Modeling result (Ex.2). Deficit area is filled.

Figure 5: Modeling result and actual scene.

4 Results

Arranging scanning lines of the main scanner next to each other according to the speed derived, we can finally obtain the 3-D model of targeted scenes.

4.1 Modeling result example

We practically operated the ladder-type laser scanning system for scanning The Bayon Temple, as a part of scanning mission in our laboratory.

Fig. 5(a) shows one example of the modeling result obtained from our system, and its actual scene. An approximate spatial width allowed for setting any devices is only 1m, meanwhile, height of the targeted scene is about 3m. Therefore it is hard to capture all of the scene at once by ordinary camera, leading to the photo in (b), however just by operating our system once in 6 seconds, we can get the modeling result.

Another example is (c). Deficit area was successfully filled by our system.

4.2 Evaluation

In order to confirm accuracy of the modeling result based on the estimated speed, we performed comparisons under two different conditions.

First, we compared the modeling result by our system with a 3-D model obtained from a fixed range scanner, Cyrax 2500 [1], by aligning them with Oishi's fast alignment algorithm[8]. As Fig. 6 shows, for most points in

[1]Measurement error of the Cyrax 2500 is about ± 5mm, which can be regarded as accurate enough.

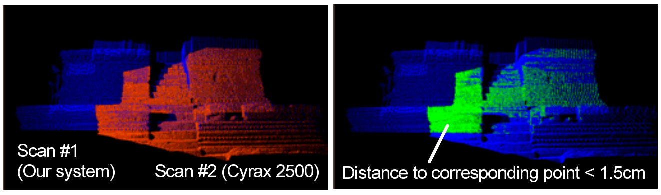


Figure 6: Comparing 3-D models obtained from our system and Cyrax 2500.

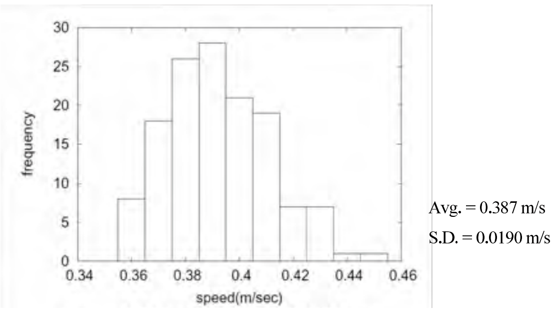


Figure 7: Histogram of estimated speed.

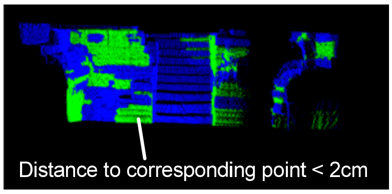
overlapping areas between two models, distance to corresponding point (the nearest neghbor point in the counter model) became less than 1.5 cm.

Secondly, we compared two modeling results obtaind by our system. The histogram in Fig. 7 shows that the estimated speed varies from case to case. Comparing two models resulted from different values of estimated speeds will also be effective to prove accuracy of each model. Fig. 8 shows result of alignment: These are cases when the moving platform is assumed to move in (a) the specified speed, or (b) our estimated speed value. In (b), for most points in overlapping areas, distance to corresponding point became less than 2 cm.

5 Conclusion

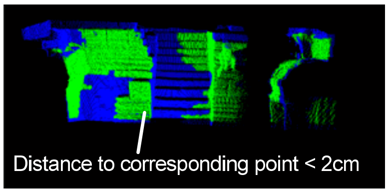
In this paper, we proposed a new type of scanning system named ladder-type laser scanning system to scan areas too narrow for ordinary commercial scanning systems. While the localization of the sensor in a specific time is one of the general problems in remote sensing, by using a scan parallel to movement, we succeeded in obtaining accurate speed of the moving sensors on a ladder in most cases, avoiding error accumulation and dispersing them throughout the whole scan.

The system was practically used for scanning Bayon Temple as a part of digital archiving project. Modeling results showed that the localization was accurate enough, since the alignment of the 3-D model by our system and 3-D model acquired from a fixed sensor corresponded well. Also, 3-D models obtained by our system with different values of estimated speed matched well, which proves the



Speed [m/s]	
Scan #1	Scan #2
0.417 (Catalog spec)	*0.417 (Catalog spec)*

(a) When using specified speed value.



Speed [m/s]	
Scan #1	Scan #2
0.391 (Estimated val.)	0.363 (Estimated val.)

(b) When using estimated speed value.

Figure 8: Comparing 3-D models both obtained from our system, but with different values of estimated speed.

accuracy of the derived speed.

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