3D Measurement of Large Structures with a Ring Laser and a Camera Using Structure from Motion for Integrating Cross Sections

Hiroshi Higuchi*1, Hiromitsu Fujii*1, Atsushi Taniguchi*2,
Masahiro Watanabe*2, Atsushi Yamashita*1, Hajime Asama*1
*1Department of Precision Engineering, The University of Tokyo
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan
*2 Hitachi, Ltd., Research & Development Group
292 Yoshida-cho, Totsuka-ku, Yokohama-shi, Kanagawa 244-0817, Japan

In assembling large structures such as railway vehicles, escalators, and elevators, 3D measurement is important for verifying that parts are attached accurately. In this paper, a method to measure the 3D shape from the inside is proposed. Accurate cross-section shapes, obtained by the light-section method, are integrated in a new way with Structure from Motion using a laser. Further, an optical filter and a new block matching technique are introduced to avoid the influence of laser light on images while integrating the cross-section shapes. In a measurement experiment conducted inside a hall, the validity of the proposed method was confirmed.

1 Introduction

3D measurement is important for manufacturing large structures such as railway vehicles, escalators, and elevators. In the assembly process of railway vehicles, skilled mechanics measure the large structure manually. This is because assembly precision must be of millimeter order or smaller. Automation of high-accuracy 3D measurement system would make such a process easier.

The popular light-section method enables accurate 3D measurement. In this method, the target object is irradiated with a laser slit light and captured by a camera. Although the 3D position of the irradiated points can be calculated by triangulation, what can be obtained are just the relative positions of the points with respect to the camera. For measurement of consistent 3D structure of wide range, it is necessary to integrate the results of the light-section method by estimating the absolute pose change.

Structure from Motion (SfM) is used for pose estimation in a lot of previous research [1][2]. SfM is a method that determines 3D motion of a camera and the structure of objects when corresponding features are captured from different poses. In [1], two images are captured by toggling the illumination and the laser light for each state. One image, used for light-section method, is captured with illumination off and laser light on, and the other, used for SfM, is taken with illumination on and laser light off. In the manufacturing environment that our research expects, it is difficult to manipulate the illumination. Therefore, a new method to integrate cross sections by SfM without manipulating illumination is proposed.

2 Method

2.1 Outline of method

In our method, 3D structures are measured by the process shown in Figure 1, and a measurement device is composed of a camera, a ring laser, and a color filter. The camera and the laser are fixed relatively, and the filter is inserted between the camera and the lens. The filter can cut off natural light whose wave length is close to the wave length of the laser so that we can extract the laser illuminated cross section.

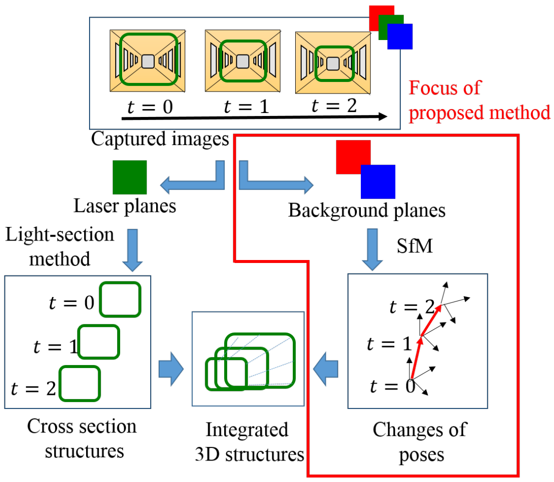

Fig. 1 Flow of the measurement method

First, an image captured through the filter is divided into two planes: the laser plane and the object plane, according to their RGB channels. The laser plane, in which only laser light is reflected, is used for the light-section method, and the object plane, created by removing laser light from the raw image, is used for SfM.

Secondly, the structures of the laser light cross sections are measured by light-section method from laser planes.

Thirdly, pose change of the measurement device is estimated. Direction of translation and rotation of movement can be calculated by SfM. However, the amount of translational movement can not be acquired because of the scale indetermination. Therefore, scale determination is conducted for pose estimation by detecting corresponding points from areas irradiated by the laser.

Finally, the results of light-section method are integrated into 3D structures by the estimated movement of the device.

In the following sections, the method of pose estimation by SfM is explained.

2.2 Pose estimation using Structure from Motion

To conduct SfM, corresponding points are searched between two consecutive frames. Feature points are detected in both frames by the Scale-Invariant Feature Transform (SIFT) descriptor, and points whose feature values are similar to

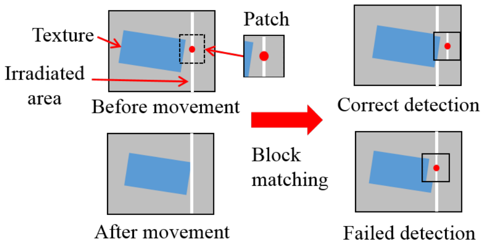

Fig. 2 Example of normal block matching affected by the laser

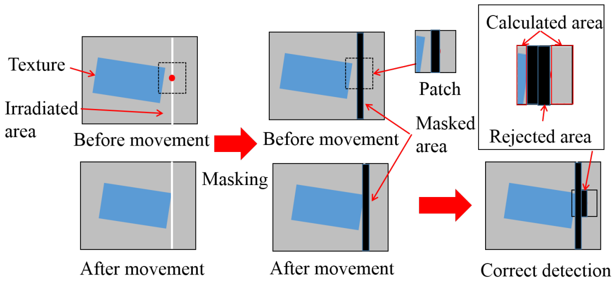

Fig. 3 Proposed block matching invariant to the laser

each other are detected as corresponding points.

In this process, areas irradiated by the laser are rejected as candidates of feature detection. Laser areas and background move in different way in the captured images because the source of the laser moves in the environment with measurement device.

SfM can be conducted using these corresponding points. Rotation and direction of translation between two frames are estimated.

2.3 Scale determination

The movement distance is obtained by tracking points irradiated by the laser whose 3D position is known beforehand from the light-section method.

Block matching is used to detect such corresponding points based on texture information of non-irradiated areas because feature detection from irradiated areas is difficult as described in the preceding section 2.2.

Laser influence must be removed to conduct correct block matching. If the irradiated areas are used for matching, incorrect results will be obtained as shown in Figure 2. Therefore the process in Figure 3 is conducted. First, the laser areas are masked both before movement and after movement image. Next, the irradiated points are selected and a patch, including the selected point, is cut out from the image captured before movement. Block matching is conducted by overlapping the patch on the image captured after movement image and calculating the Zero-mean Normalized Cross Correlation (ZNCC). When ZNCC is calculated, pixels unmasked in both images only are included. Corresponding points can be obtained by searching for the patch with the highest ZNCC.

Fig. 4 Target environment

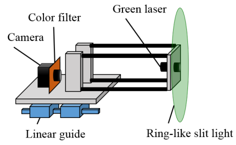

Fig. 5 Experimental device

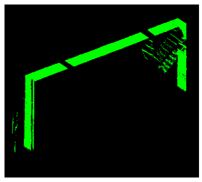

Fig. 6 Using known motion

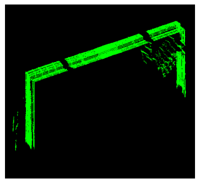

Fig. 7 Using estimated motion

3 Experiment

3.1 Experimental environment

The target of measurement was a corridor, shown in Figure 4. The proposed device was attached on a linear guide in the experiment as shown in Figure 5. Images were captured by moving the device with the linear guide. The device moved 180 mm normal to the laser plane, capturing images in 10 mm intervals. The light-section method was conducted for all frames, and pose estimation was conducted for every three frames. The results of light-section method were integrated by movements in 10 mm intervals inferred by linear interpolation in 30 mm intervals.

3.2 Results

The results of the experiment are indicated in Figures 6 and 7. Structures of cross sections were integrated by the known movement of the linear guide in Figure 6, and by the information of pose estimation in Figure 7. It is confirmed that 3D model can be constructed by the proposed method from Figure 7.

4 Conclusion

A new method for the 3D measurement of large structures from the inside by integrating the results of the light-section method using SfM is proposed. To conduct SfM and the light-section method from the same image, a color filter and original block matching technique are introduced.

Future work is the improvement of measurement accuracy. It is necessary to detect corresponding points used for SfM and scale determination more robustly for more accurate measurement.

References

[1] A. Yamashita, K. Matsui, R. Kawanishi, T. Kaneko, T. Murakami, H. Omori, T. Nakamura and H. Asama, " Self-localization and 3-D model construction of pipe by earthworm robot equipped with omni-directional rangefinder ", *Proceedings of the 2011 IEEE International Conference on Robotics and Biomimetics*, pp.1017–1023, 2011.

[2] A. Duda, J. Schwendner and C. Gaudig, "SRSL: Monocular Self-Referenced Line Structured Light", *Proceedings of the 2015 IEEE/RSJ International Conference on Intelligent Robots and Systems*, pp. 717-722, 2015.