Lidar Upsampling Using HSD Color Space Guided Image

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***Abstract*—This paper proposes a 3D spatial upsampling algorithm using a 2D LiDAR and a single camera. These two devices are placed on the same line, and both data are acquired by rotating the stage 360° around a vertical axis using a step motor. The obtained data is used to calibrate between the LiDAR and the camera. And a high-density 3D map is generated through a proposed two-step upsampling method using HSD-based guide image.**

Keywords—2D LiDAR; Single camera; Calibration; HSD channel; Upsampling; 3D reconstruction

I. INTRODUCTION

A 3D spatial precision scanning device can be effectively used for service development using 3D spatial information contents such as buildings or indoors. In addition, it is possible to effectively cope with a disaster situation by generating a high-resolution 3D spatial map in a short time in a space where people cannot easily enter, such as building collapses, large fire, radioactive material leak, etc.

This paper proposes a 3D spatial upsampling method using a 2D LiDAR and a single camera. These two devices are placed on the same line, and both data are acquired by rotating the stage 360° around a vertical axis using a step motor. The obtained data is used to calibrate between the LiDAR and the camera. In addition, a high-density 3D map is generated through a proposed two-step upsampling method using HSD-based guide image. To acquire the data, the Omni-directional scanning device introduced in [1] was used. The configuration of the device is shown in Fig. 1.

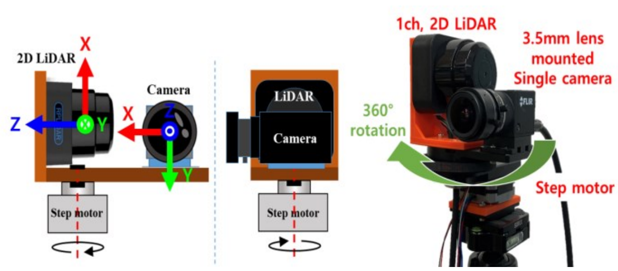


Fig. 1. 3D scanning device

II. EXPERIMENTAL METHOD

A. Camera-LiDAR Calibration

Calibration between the camera and the LiDAR is performed to fuse the color information of the camera and the 3D point cloud information of the LiDAR.

1) Extraction of 3D Chessboard Plane using Camera Image Information and LiDAR Point Cloud

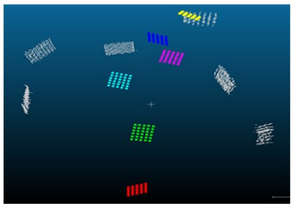
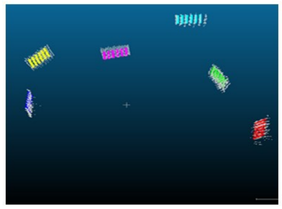
a) Setting an arbitrary 3D corner coordinates in the world coordinate system, and transforms through a [2] PnP (Perspective-n-Point) algorithm in the camera coordinate system. At this time, it can be seen that the extracted 3D corner points are on the plane of the chessboard. Each plane is rotated as much as the camera rotates using the information of the angle that the stepper motor rotates along the vertical axis.

b) Extract a 3D point cloud from the LiDAR. The LiDAR output based on the spherical coordinate system is expressed as the Cartesian coordinate system in Equation (1). d is the distance from the center of the lidar sensor to the object and ϕ is the angle the stepper motor rotates in the horizontal clockwise direction. θ is the clockwise angle of the lidar. The plane of the chess board is detected from the extracted 3D point cloud.

$$\begin{aligned} x &= d \cdot \sin(\phi) \cdot \cos(\theta) \\ y &= d \cdot \sin(\phi) \cdot \cos(\theta) \\ z &= -d \cdot \sin(\phi) \ \ (0 \leq \phi < 2\pi), (0 \leq \theta < 2\pi) \end{aligned} \tag{1}$$

2) Calibration of Coordinate System using 3D Plane Information and ICP (Iterative Closest Point) Algorithm[3]

a) Fig. 2(a) is an example of visualizing an uncorrected camera and lidar plane with a 3D viewer. In this paper, we estimate the 3D transformation matrix between the two devices by matching the two planes extracted from the camera and lidar using the ICP algorithm. In order to minimize the error of the two corrected planes, ICP algorithm is applied after matching the initial 3D registration position. Fig. 2(b) is an example of visualizing the calibrated 3D plane.

(a) (b)

Fig. 2. 3D camera chessboard corners (colored), LiDAR (white) chessboard plane data. (a) Before plane calibration, (b) After plane calibration

B. Depth Map First-step Upsampling

A depth map is generated by projecting 3D LiDAR data onto a 2D image through the estimated transformation matrix. For the interpolation, neighboring points of LiDAR data from the target pixel in the image are selected. Depth map interpolation according to pixel distance is performed using the selected points. Since the depth information of the area around the edge of the current depth map is not reliable due to the blur phenomenon, Onion-Peel Filtering introduced in the paper [4] is applied. After the depth information of the area around the edge is removed, the discontinuity of the edge area is identified and refined through estimation of filling the depth value of the external pixel that has not been removed inside. Since it is difficult to estimate the depth value of the pixels, which have small depth difference from nearby pixels, we refer to an edge periphery of the RGB image of the camera. Fig. 3 shows the area around the edge of the depth map to be refined. Fig. 4 is a 360° panoramic depth map after the first-step upsampling is applied after the interpolation and refinement process has been completed.

C. Creating a Guide Image with Depth Information

Weighted Median Filter [5] is an edge preserving filter that is an improved guided image filter [6]. This filter performs filtering using color information of the guide image. In this case, when a camera RGB image without depth information is used as a guide image, an error in the depth value occurs due to a difference in color intensity of the guide image even if the distances at any two points are the same. Therefore, in order to minimize this error, depth information is added to the guide image. First, an RGB channel image is converted into an HSI channel. The intensity value of the converted image is replaced with the depth value of the depth map completed until

Fig. 3. Area around the edge of the depth map to refine

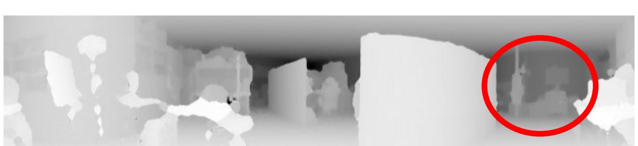


Fig. 4. First-step upsampled 360° panoramic depth map

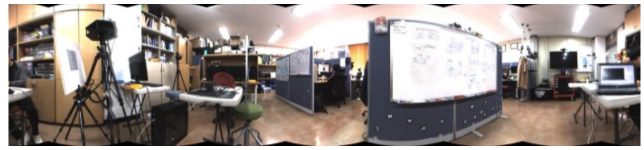


Fig. 5. Original panoramic guide image

Fig. 6 Final panoramic guide image with depth information

interpolation. The image of the replaced HSD channel is converted back to the RGB channel. Fig. 5 is the original guide image, and Fig. 6 is the final guide image including depth information.

D. Depth Map Second-step Upsampling

Second-step up-sampling is performed by applying a weighted median filter based on the extracted first-step up-sampled input depth map and guide image including depth information. After obtaining the interval from the minimum distance measured in the depth map to the maximum distance, the interval was divided into 1024 layers and filtered. When the red circle in Fig. 4 is enlarged, Fig. 7(a) is a depth map after applied the first-step upsampling, and (b) is a depth map after applied the second-step upsampling.

(a)

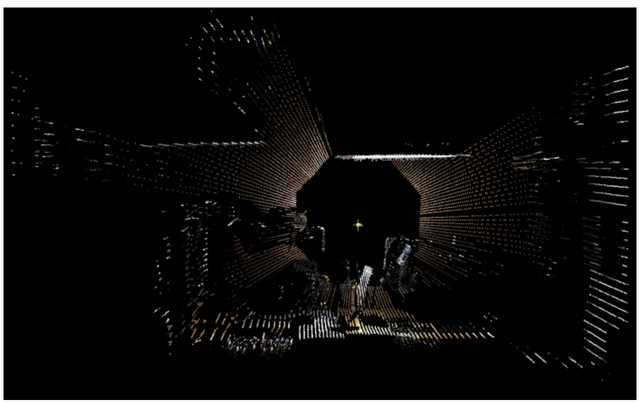
(b)

Fig. 7 Upsampled depth map, (a) after first-step (b) after second-step

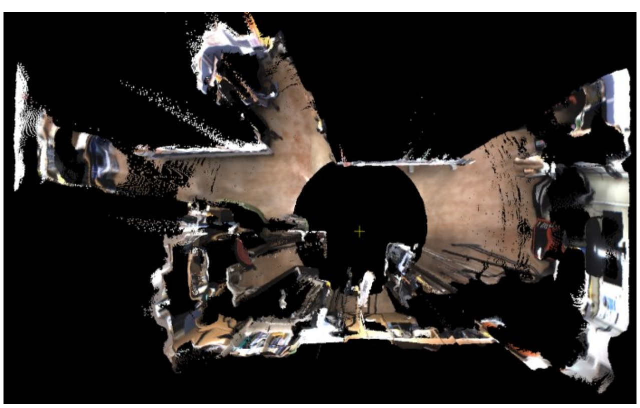
III. Experimental Result

We performed an experiments to evaluate the accuracy of our proposed upsampling method using the Omni-directional scanning device configuration shown in Fig. 1.

A 2D LiDAR with a scanning period of about 10 Hz was rotated at an angular speed of 0.1 rad/s on a stepper motor and projected onto a panoramic space with a resolution of 3600 * 821 pixels. In other words, the original LiDAR data was formed in 200 lines vertically at an interval of about 1.8° in the panoramic space. The original guide image was taken with a single camera at 45° intervals, 8 shots and warped on a panoramic space with the same resolution. As shown in Fig. 2(b), the result of calibration between the camera and LiDAR, there was a matching error of around 1 cm. Fig. 8(a) is a top view of our lab's 3D original data taken in one place. For comparative convenience, the ceiling was removed. Fig. 8(b) is the final 3D reconstructed data completed up to the proposed upsampling. Fig. 9 is an enlarged view of the part of Fig. 8. Fig. 9(a) is the 3D original data, and Fig. 9(b) is the final 3D reconstructed data completed up to the proposed upsampling.

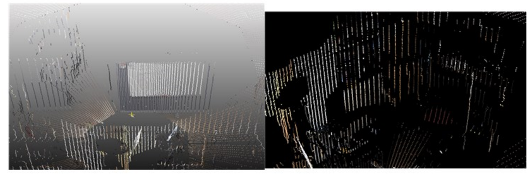


(a)

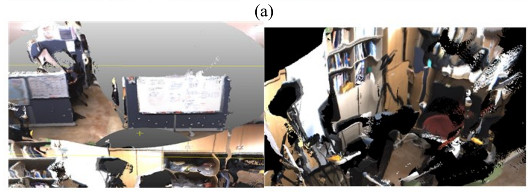


(b)

Fig. 8. 3D reconstructed data comparison before (a) and after (b) upsampling (ceiling removed)



(a)



(b)

Fig. 9. 3D reconstructed data comparison before (a) and after (b) upsampling

IV. Conclusions

In this paper, Calibration between the camera and the LiDAR is performed to fuse the color information of the camera and the 3D point cloud information of the LiDAR. In addition, a high-density 3D map was created by applying the proposed two-step upsampling method using HSD-based guide image. First, first-step upsampling of the depth map is performed to interpolate and refine the data of the depth map. Then, in order to add depth information to the guide image, the intensity value of the guide image is replaced with the depth value of the depth map completed until interpolation. Finally, second-step up-sampling is performed by applying a weighted median filter based on the extracted first-step upsampled input depth map and the guide image. In the future, the refinement process during the first-step upsampling will be improved to generate more accurate 3D maps.

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