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Improving of 3–D structure estimation methods by image using ambient light

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Abstract
Ambient light is a concept proposed by visual affordance theory that refers to the distribution of light a single viewpoint receives from its surroundings. By observing the changes in the luminance distribution of light produced by the structure of the environment from a single viewpoint, we can estimate the surrounding structure. When we apply this natural mechanism of recognizing the outside world to image measurement technology, it is possible to obtain the information necessary to recognize the surrounding environment by observing the ambient light without necessarily detecting or recognizing the object. For example, this methods can be used to estimate the 3-D structure in an image using only simple algorithms, without the need for complex image processing or prior data for machine learning. In a previous study, we proposed a structure estimation method to understand the structure of the surrounding environment by capturing ambient light as luminance, thus providing a viewpoint in an indoor environment. The layout of the surface of the surrounding environment structure is estimated by assuming that a horizontal wall is a vertical wall and a vertical wall is a horizontal wall, and that the indoor structure is composed of vertical walls, horizontal walls, and space. However, this method sometimes failed to estimate the structure correctly because changes in the position of the lighting in the room affected the estimation results. In addition, it sometimes misrecognized the boundary of the surface when estimating the structure. In contrast, by using the dynamic thresholding method proposed in the current study, we were able to obtain results that were robust to changes in illumination position. In addition, by focusing on the presence or absence of luminance continuity in an image, we were able to accurately detect the boundary of the surface. In this paper, we describe these results of improving the 3-D structure estimation method.

Keywords: Image, Estimating, Structure, Improvement

1. Introduction

Mobile robots that run autonomously in unknown environments are required to estimate their own position, recognize obstacles, and plan their actions to reach a desired destination. In many studies, image measurement has been used for the target extraction process necessary to complete such activities. However, this requires the processing of a huge amount of information (e.g., feature quantities) in which the computations are complicated, making it difficult to improve the speed of the image processing. Furthermore, measurement becomes difficult when training data cannot be prepared in advance, such as in an unknown environment. Gibson proposed the visual affordance theory, which states that, regarding the relationship between the movement, form, and function of the organism, "the environment gives a certain meaning to the organism," [1–3] and pointed out the importance of the structure of light incident on the eyes of the organism, called "ambient light." For example, when moving through a space surrounded by walls, the use of ambient light allows us to recognize the walls as a surface structure without using complex image processing.

2. 3-D Structure Estimation Methods

The authors have previously proposed a method for estimating environmental structure using ambient light, as shown in Figure 1 [4]. From the array of luminance captured as ambient light from the captured image, we estimate the angle that is the boundary (structural turning point) of the surface structure of the surrounding environment. The region sandwiched between the structural boundary points is presumed to be one continuous surface. Next, because the gradation of luminance becomes surface and depth information, the orientation of each surface is estimated from the change in luminance. Finally, we estimate the surrounding environmental structure by combining the surfaces whose orientations are estimated with the presence or absence of space at the turning points of the structure.

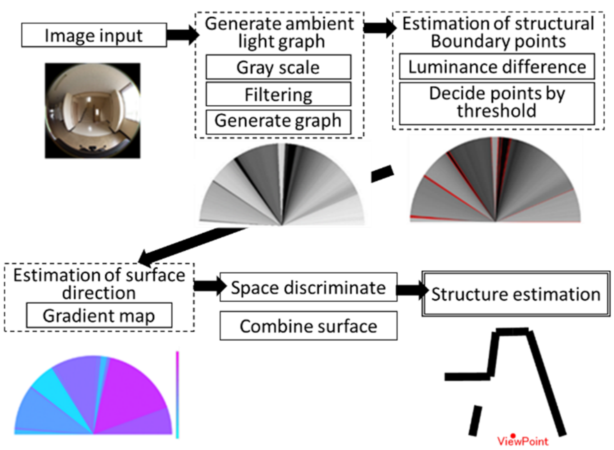


Figure 1. Process of structure estimation method [4].

We can roughly estimate the structure when the light source is positioned inside the structure, and it is possible to estimate the structure when the light source is positioned within π/8 rad of a circle with respect to the camera's optical axis. However, depending on the lighting arrangement and the positional relationship between the lighting and the target structure, the target structure might not be estimated accurately in some cases. For the practical application of this system, it is necessary to improve the method so that it is less sensitive to the lighting arrangement.

3. Improvement by Dynamic Thresholding

In our previous method, depending on the lighting arrangement, the structural boundary points might not be detected, as shown in Fig. 2. To solve this problem, we applied dynamic thresholding to the captured images to obtain the structural boundary points by edge processing. Figure 3 shows a comparison of the proposed method and the conventional method. By using dynamic thresholding, we were able to detect structural boundary points even in lighting arrangements where structural boundary points could not be detected in the past. However, in some cases, more points than the actual number of structural boundary points were falsely detected.

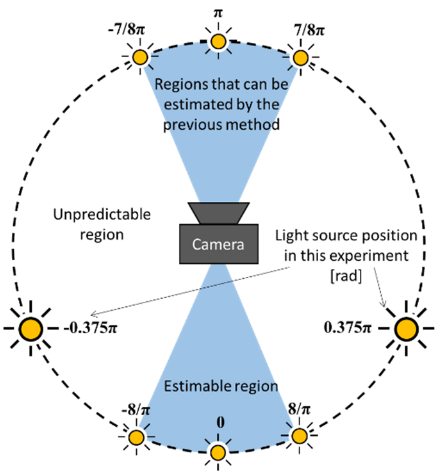
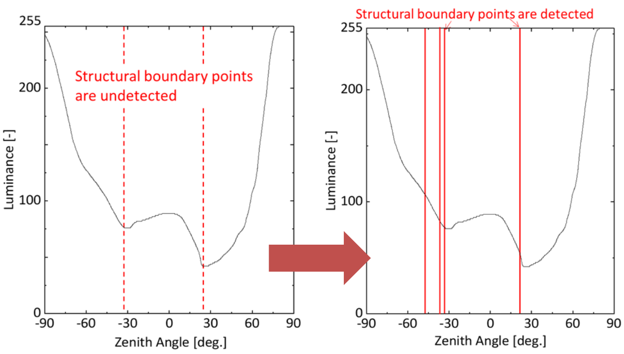


Figure 2. Light source position.

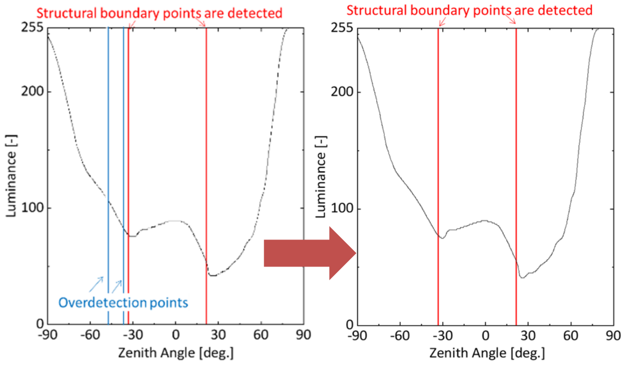


(a) Without dynamic thresholding **(b)** With dynamic thresholding

Figure 3. Detection of structural boundary points.

4. Improvement using Change in Surface Luminance

To reduce the over-detection of structural boundary points when using dynamic thresholding, we investigated a method for correctly determining the structural boundary points by focusing on the continuity of the luminance gradient in the area sandwiched by the structural boundary points. The region sandwiched by the correct structural boundary points should be a wall-like surface or an open space such as a doorway. In this case, the correct structural boundary points are determined by estimating the surface or space according to whether the gradient of luminance is continuous or discontinuous. Figure 4 shows a comparison of the proposed method and the conventional method, where we can see that the proposed method was not affected by the lighting arrangement and could correctly determine the structural boundary points. Using the new method, we were able to correctly estimate complex T-junctions, as shown in Figure 5. As a result, we were able to extend the range of illuminations that yielded correct structure estimation results.



(a) With dynamic thresholding **(b)** Using luminance continuity and dynamic thresholding

Figure 4. Comparison of new and conventional methods

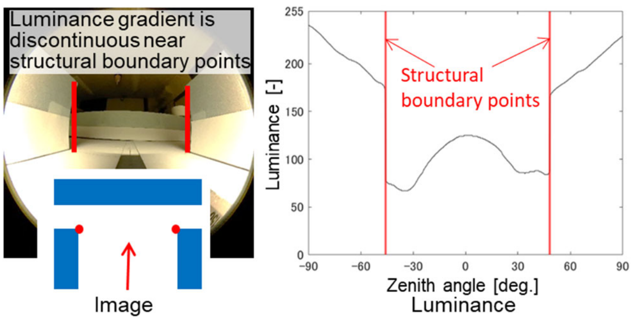


Figure 5. Detection results of structural boundary points (T-junction).

5. Conclusion

In the previously proposed method of estimating the surrounding structure using ambient light, the target structure was not always estimated accurately depending on the lighting arrangement and the positional relationship between the lighting and the target structure. Therefore, we investigated the use of dynamic thresholding combined with the continuity of the luminance gradient in the previous method. Our findings showed that the proposed method is not affected by the lighting arrangement and can correctly determine the structural boundary points. As a result, the range of illuminance at which correct structure estimation results were obtained was expanded, and the structure estimation method using ambient light was improved.

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