Removal of Reflection from Nightscape Parallel Stereo Images of Distant View through Window

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***Abstract*—Camera images taken through window glass sometimes have a problem of reflection from the glass surface. It is conspicuous in night scenes because reflection intensity is considerable compared to the outside objects. This paper proposes a removing method of reflections of a planar object from night scene images taken through a window glass. Two different view point images are taken with parallel stereo camera. In the acquired images, the disparity of night scene is considered to be zero if the scene is of a distant view. In this paper, we treat the case that the relative positions of reflection and night scene in stereo images are known and the disparity appears only in the reflection as a predictable value. By calculating the pixel values of the relative position, the reflection is removed. Experimental results showed the effectiveness of the proposed method.**

***Index Terms*—Stereo Camera, Nightscape Image, Reflection.**

I. Introduction

Camera images taken through window glass sometimes have a problem of reflection from the glass surface. This phenomenon is conspicuous in night scene. Fig. 1 shows an example of a night scene with reflection.

Night scenes can be seen from observatories and high-rise buildings. In these places, we take a picture through window glass. In this case, it is difficult to take a picture of night scene without the influence of reflection. Therefore, it is desirable to provide a method that can obtain the night scene from images taken through a window glass.

There has been a method proposed for removing adherent noises like waterdrops or mud blobs from images taken in a rainy day [1]. This method uses interpolation of images taken with a stereo camera. However, this method cannot remove noises when the same object is interrupted in multiple cameras. A method of removing a wire net from a picture taken through the wire net was proposed [2], [3]. However, this method needs to know the ground truth of the wire net.

Removal methods of reflection using polarizing filter have been proposed [4], [5], [6]. These methods use the property that the reflected light is polarised. They need to take multiple images of various intensity of reflection which are obtained by rotating polarizing filter. Other methods using independent component analysis [7], [8] and focus [9] have been proposed. These methods also need to take multiple images.

In this paper, we propose a method for removing reflection using a stereo camera. The purpose of the proposed method is to obtain a nightscape image in which a reflection is removed by using two images. Stereo camera takes two different images at a time. Therefore, unlike the other methods using multiple images, the proposed method can obtain necessary images in a single shoot.

Fig. 1. Example of reflection.

In the following sections, theoretical explanations and experimental results of proposed method are given.

II. Image Acquisition

Geometrical relationship in image acquisition is shown in Fig. 2. The proposed method captures stereo images of night scene with two cameras. As a preliminary study, the following conditions are assumed.

(1) The stereo camera system has a parallel stereo setup.
(2) Night scene is a distant view, and there is no disparity in the stereo pair.
(3) Reflection objects are planar and placed behind the camera.
(4) Every scan line in the image has a consecutive region without reflection.

III. Disparity of Reflection

The proposed method removes the reflection using the disparity of the reflection. Therefore, it is necessary to determine the disparity of each pixel in the acquired images. The disparity of reflection is constant when the reflection and the baseline of the cameras are parallel to the window surface. If they are not parallel, the disparity changes according to the distance from the reflection to the baseline of the cameras. Equation (1) shows the relationship between the distance from the camera baseline and the disparity.

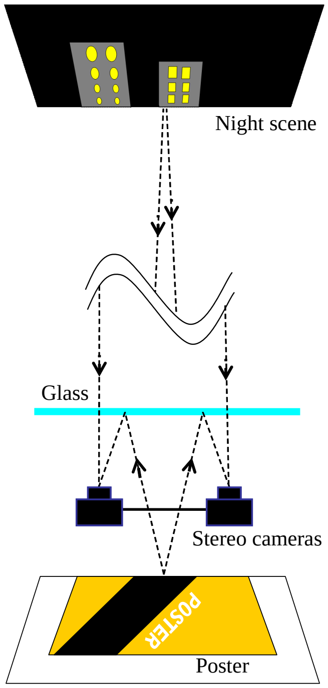


Fig. 2. Geometrical relationship in image acquisition.

$$d = \frac{f \cdot L}{Z} \tag{1}$$

where d is a disparity, f is the focal length, L is the baseline length and Z is the distance from the reflection to the baseline. From the assumption that the reflection and the glass surface are planar, the distance changes linearly with the horizontal position in the image. Fig. 3 shows a graph of the example of the relationship between the horizontal positions of the images and the disparity. By indicating two pairs of corresponding points of the reflection in acquired stereo images, the disparity of each pixel of the reflection is determined.

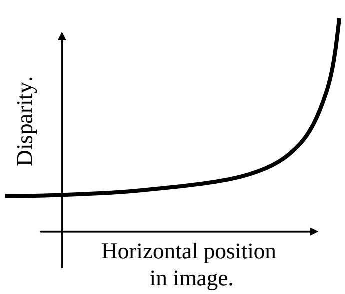


Fig. 3. Example of a relationship between horizontal positions of the images and the disparity.

IV. Removal of Reflection

In the stereo images, the night scene and the reflection is superimposed. Fig. 4 (a) shows an example of captured image in environment of Fig. 2. The pixel value of acquired image is linearly superimposed of a pixel value of night scene (Fig. 4 (b)) and a pixel value of reflection (Fig. 4 (c)). Equations (2) and (3) show these relationships.

$$I^L(x, y) = I_f^L(x, y) + I_b(x, y) \tag{2}$$

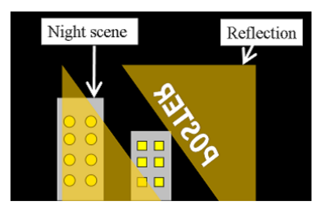
$$I^R(x, y) = I_f^R(x, y) + I_b(x, y) \tag{3}$$

where x and y are horizontal and vertical positions of image, $I^L(x, y)$ and $I^R(x, y)$ are pixel values of captured stereo images, $I_f^L(x, y)$ and $I_f^R(x, y)$ are pixel values of reflection, and $I_b(x, y)$ is a pixel value of night scene. A pixel value of night scene is the same in left and right images because the disparity of night scene is zero. Equations (2) and (3) are rearranged to (4) and (5) by using a disparity of reflection d.

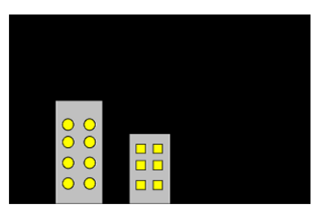
$$I_b(x, y) = I^L(x, y) - I^R(x - d, y) + I_b(x - d, y) \tag{4}$$

$$I_b(x, y) = I^R(x, y) - I^L(x + d, y) + I_b(x + d, y) \tag{5}$$

The proposed method assumes that the reflection is not contained at $I_b(0, y) \sim I_b(d-1, y)$ of the acquired left image (Fig. 4 (d)) and $I_b(N-1, y) \sim I_b(N-d, y)$ of the acquired right image (Fig. 4 (e)) where N is the number of pixels along the horizontal axis. The pixel value $I_b(0) \sim I_b(d-1)$ of the night scene of left image is given from the acquired left image. The pixel value of remaining region is calculated using (4).

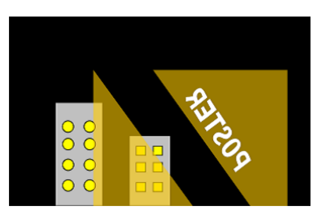


(a) Acquired image.



(b) Night scene.

(c) Reflection.



(d) Left image.

(e) Right image.

Fig. 4. Example of images.

(a) Acquired image of left.

(b) Acquired image of right.

(c) Night scene of left.

(d) Night scene of right.

Fig. 5. Accumulated noise of calculation.

Similarly, the night scene of right image is calculated from the acquired right image using (5).

Equations (4) and (5) are calculated by using the value of pixel whose position in the image has offset d in the night scene. If a noise appears in calculation, accumulation of the noise becomes a problem. An example of a noise is shown in Fig. 5 (a) and (b). Fig. 5 (a) and (b) show the acquired stereo images. Buildings and a red reflection object are photographed. Fig. 5 (c) and (d) shows a removal result in which a spurious images appears.

In order to reduce the above noise, we use the regions which do not contain the reflection. A pixel value of such regions becomes small because it is a linear superimposition of a pixel value of the night scene and a pixel value of the reflection. In the regions like a night sky, the pixel value of the night scene seems to be small. Therefore, we assume that the regions of small pixel value in acquired images do not contain the reflection. We call it a night scene region. The night scene region of Fig. 4 (d) and (e) is shown in Fig. 6 in black.

In the night scene region, a pixel value of the night scene is directly given from the acquired image. Therefore, it is possible to reset the accumulated noise of calculation by using pixel values of these regions as initial values in (4) and (5).

In addition, the noise is reduced by alpha blending of the left and right night scenes. In the left image, the noise accumulates as a pixel goes from left to right side of the image. Therefore, the weighting factor on the left side should be large and on the right side it should be small. Equation (6) shows a calculation for alpha blending.

$$I_b(x) = (1 - \alpha) \cdot I_b^L(x) + \alpha \cdot I_b^R(x) \tag{6}$$

where $I_b^L(x)$ and $I_b^R(x)$ are the night scene of the left image and the right image respectively, and α is the weighting factor.

Based on the above, the processing procedure of proposed method is shown below.

1) Estimate disparity d of the reflection from the acquired images.
2) Find the night scene region from the acquired images.
3) Give pixel values $I_b(0, y) \sim I_b(d - 1, y)$ and $I_b(N - 1, y) \sim I_b(N - d)$ to the night scene from the acquired images. Give pixel values of the night scene region to the night scene from the acquired images, too.
4) Calculate the pixel values of remaining regions of the night scene using (4) and (5).
5) Calculate the pixel value of the night scene of alpha blending from the night scenes of the left and the right images.

V. Experiment

We performed experiment to confirm the validity of the method. Environment of image acquisition is shown in Fig. 7. The size of image was 1400×800 pixels. The reflection objects are shown in Fig. 8.

A. Simulation

For simulation, a case where reflection, glass surface and the camera baseline are strictly parallel to one another was examined.

Fig. 9 shows acquired stereo images. Gaussian noise was added to the left and right images. Fig. 10 show the extracted night scene region. The night scene region is shown in black. Fig. 11 shows the night scene calculated by (4) and (5). In simulation, the proposed method removed the reflection well.

(a) Left.

(b) Right.

Fig. 6. Night scene region.

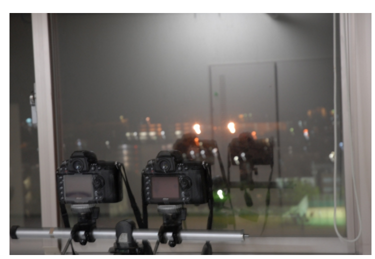


Fig. 7. Environment of image acquisition.

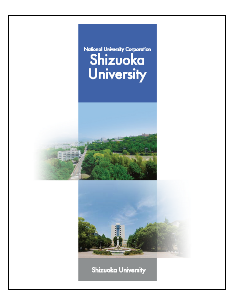
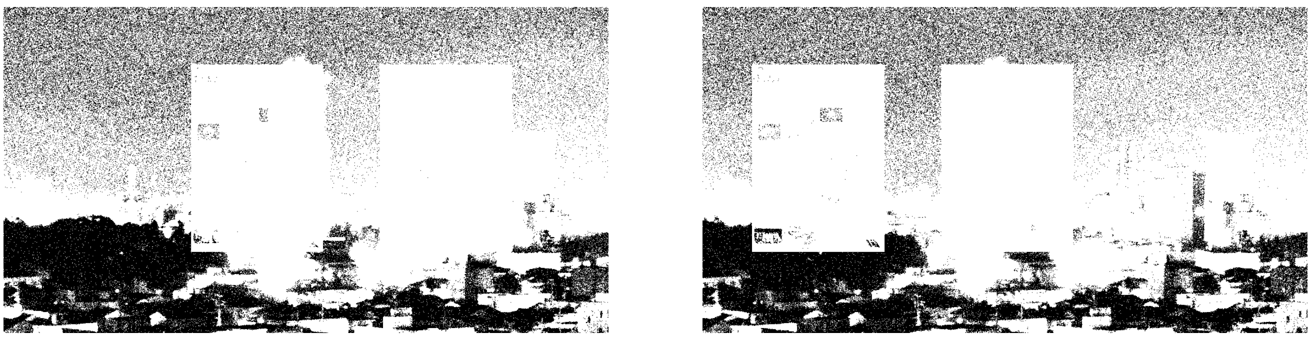


Fig. 8. Reflection objects.

(a) Left image. (b) Right image.

Fig. 9. Acquired images.



(a) Left image. (b) Right image.

Fig. 10. Night scene region.

B. Results using actual images.

In this case, reflection and glass surface and the camera baseline were not strictly parallel.

Fig. 12 shows acquired images. Fig. 13 shows the extracted night scene region. Fig. 14 shows the night scene calculated by (4) and (5). Fig. 15 shows the night scene of alpha blending. The noise was caused by the difference of position.

Fig. 16 shows the ground truth of the night scene. Fig. 17 shows the difference images of the acquired left image and the ground truth. Fig. 18 shows the difference images of the night scene of alpha blending and the ground truth. Although the proposed method generated the night scene close to the ground truth, there are some noises which may be caused by misregistration of stereo images.

VI. Conclusion

In this paper, we proposed a method for removing the reflection of a planar object from the night scene image taken through a window glass using stereo camera. The experimental results showed the effectiveness of proposed method.

As future work, we should improve the image quality of night scene by reducing noises, expand our method to treat more general condition of image acquisition.

VII. Acknowledgment

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References

[1] Yuu Tanaka, Atsushi Yamashita, Toru Kaneko and Kenjiro T. Miura: "Removal of Adherent Waterdrops from Images Acquired with a Stereo Camera System", *IEICE Transactions on Information and Systems*, Vol.89-D, No.7, pp.2021-2027, 2006.

[2] Atsushi Yamashita, Akiyoshi Matsui and Toru Kaneko: "Fence Removal from Multi-Focus Images", *Proceedings of the 20th International Conference on Pattern Recognition (ICPR2010)*, pp.4532-4535, 2010.

[3] Atsushi Yamashita, Fumiya Tsurumi, Toru Kaneko and Hajime Asama: "Automatic Removal of Foreground Occluder From Multi-Focus Images", *Proceedings of the 2012 IEEE International Conference on Robotics and Automation (ICRA2012)*, pp.5410–5416, 2012.

[4] Alexander M. Bronstein, Michael M. Bronstein, Michael Zibulevsky and Yehoshua Y. Zeevi: "Blind Separation of Reflections Using Sparse ICA", *Proceedings of the 4th Symposium on Independent Component Analysis and Blind Single Separation*, pp.227-232, 2003.

[5] Yoav Y. Schechner, Joseph Shamir and Nahum Kiryati: "Polarization-based Decorrelation of Transparent Layers: The Inclination Angle of an Invisible Surface", *Proceedings of the 7th IEEE International Conference on Computer Vision (ICCV1999)*, Vol.2, pp.814-819, 1999.

[6] Noboru Ohnishi, Kenji Kumaki, Tsuyoshi Yamamura and Toshimitsu Tanaka: "Separating Real and Virtual Objects From Their Overlapping Images", *Proceedings of the 4th European Conference on Computer Vision (ECCV1996)*, Vol.2, pp.636-646, 1996.

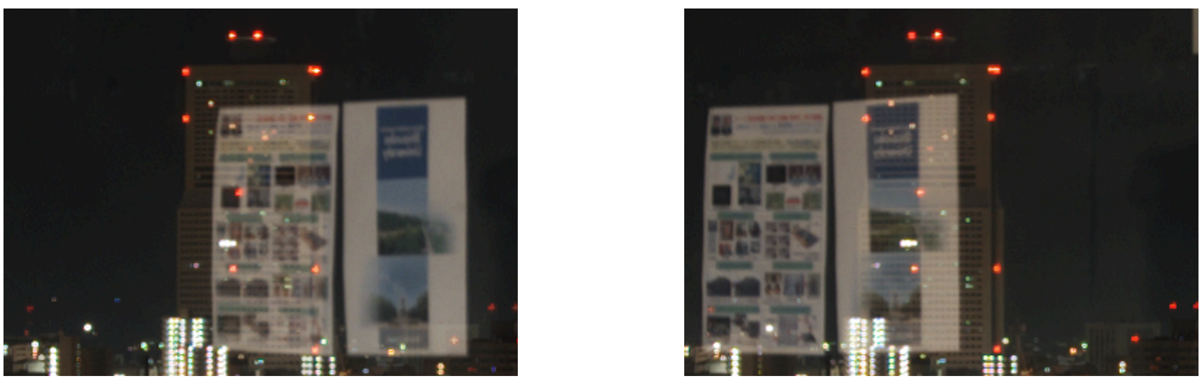
[7] Hany Farid and Edward H. Adelson: "Separating Reflections from Images Using Independent Components Analysis", *Journal of the Optical Society of America A*, Vol.16, No.9, pp.2136-2145, 1990.

[8] Hany Farid and Edward H. Adelson: "Separating Reflections and Lighting Using Independent Components Analysis", *Proceedings of the 1999 IEEE Computer Society Conference on Computer Vision and Pattern Recognition (ICCV1999)*, Vol.1, pp.262-267, 1999.

[9] Yoav Y. Schechner, Nahum Kiryati and Ronen Basri, "Separation of Transparent Layers Using Focus", *International Journal of Computer Vision*, Vol. 39, No.1, pp.25-39, 2000.

(a) Left image. (b) Right image.

Fig. 11. Night scene.



(a) Left image. (b) right image.

Fig. 12. Acquired images.

(a) Left image. (b) Right image.

Fig. 13. Night scene region.

(a) Left image.

(b) Right image.

Fig. 14. Night scene.

Fig. 15. Night scene (alpha blending).

Fig. 16. Ground truth.

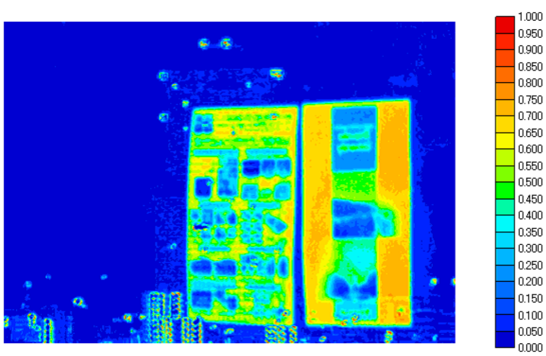


Fig. 17. Difference between the ground truth and the acquired left image.

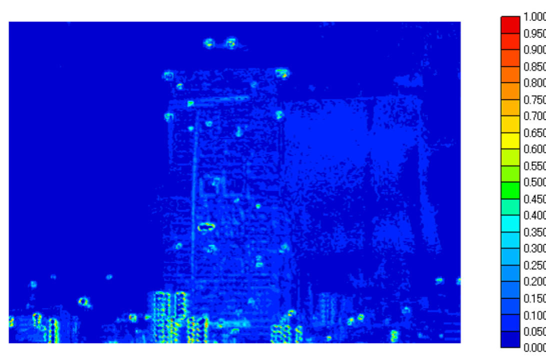


Fig. 18. Difference between the ground truth and the final image.