Restoration of Images Stained with Waterdrops on a Protection Glass Surface by Using a Stereo Image Pair

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1 Introduction

In recent years, many surveillance systems based on image processing have been developed owing to performance improvement and cost reduction in computers and image input devices. However, the quality of images taken through a camera depends on environmental conditions. Especially, in rainy days, we cannot get a clear image when waterdrops adhere to a protection glass surface and interrupt a field of view.

In order to obtain a clear image, it is necessary to detect and remove noises such as waterdrops. Many methods detect noises, based on background subtraction or inter-frame difference. Background subtraction has a disadvantage that it cannot be used in case when the background itself changes. Also, inter-frame difference has a disadvantage that it cannot detect stationary objects after they have appeared and stay in the image. A noise elimination method based on temporal median filtering has been proposed [1]. It is valid for removal of moving noise such as snowfall. However, it is difficult for these methods to detect waterdrops on the protection glass surface when the background changes dynamically.

Some methods for removal of waterdrops adhering to a protection glass surface have been proposed. One is a method for removing waterdrops using the difference between two or more viewpoint images [2]. This method is valid even when a background changes. However, since it is based on the difference between images, it cannot be used for close scenes that have disparities between different viewpoints. Another is a method that removes waterdrops using multiple images from a motion camera [3]. However, this method cannot be used when a background contains moving objects.

Therefore, in this paper, we propose a method for removing waterdrops where the above-mentioned problem of the method proposed in [2] is resolved by stereo vision, i.e., the proposed method in this paper is valid for close scenes.

2 Outline

The method consists of the following three steps.

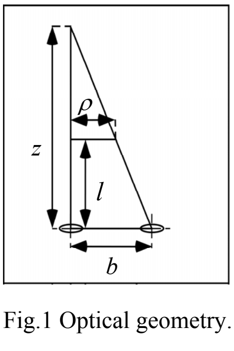
(a) It acquires parallel stereo image pair. In the case of color images, they are converted into gray-scale images.

(b) It performs template matching by normalized cross correlation between images of a gray-scale stereo pair. And it distinguishes waterdrops using disparity and correlation of each pixel.

(c) By interpolation it determines disparities of areas where disparities are not given by the matching process. Waterdrops existing in a common view of a stereo image pair are removed by replacing its pixels with the corresponding ones in the other image obtained by referring their disparities.

3 Constraint of base line length

The proposed method removes waterdrops in the common view of a stereo image pair by replacing pixels of waterdrops in one image with pixels in the other image. Cameras view direction is same by a half mirror (Fig.1). And a protection



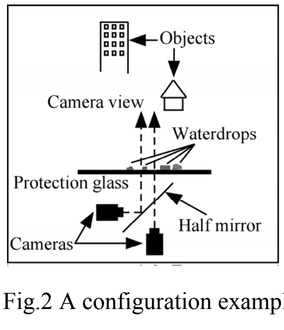


Fig.1 Optical geometry. Fig.2 A configuration example.

glass surface is set up in perpendicular in the cameras view direction. Optical geometry of cameras is shown in Fig.2, since the cameras view direction is same.

The base line length needs to satisfy Eq.(1) (Fig.1).

$$b > \frac{z\rho}{z-l} \quad (1)$$

where b, l, z and ρ denote the base-line length, the distance between cameras and a protection glass, the distance between the cameras and an object nearest to the cameras, and a waterdrop size, respectively. The waterdrop size ρ has a physical maximum limit $\rho_{\max}$. So, we can estimate the minimum of b as $b_{\min} \approx z\rho_{\max}/(z-l)$. It is impossible, however, to realize such a short baseline length in used stereo camera configuration. Figure 2 shows an example of configuration using a half mirror to solve this problem.

4 Detection of waterdrop positions

The method performs template matching by normalized cross correlation of the stereo images. Then it acquires disparities and correlations, and determines waterdrop positions.

4.1Detection by one-to-one correspondence

The method detects positions of waterdrops using disparities that are obtained by template matching of stereo images. Template matching causes errors, when intensity variation in a template is little, or when a matching point does not exist by occlusion. Therefore, it is necessary to investigate a reliability of template matching results. In order to investigate the reliability, two criteria are adopted here. One is thresholding of correlations. If a correlation R is less than a threshold C, the matching result is discarded as unreliable.

The other criterion is investigating whether results of template matching correspond one-on-one. If a matching result is correct, it corresponds one on one.

Suppose that a pixel at (u,v) in one image is set as a center of a template, and a matched pixel is found at (u',v) in the 2nd image. Next, template matching is again performed by setting a pixel at (u',v) in the 2nd image as a center of a template. The result has one-on-one correspondence only when $u = u''$, where (u'',v) is the coordinates of the matched pixel in the 1st image. However, we should give some tolerance for this condition because of image noise. Pixel (u,v) is given a judgment value $\gamma(u,v)$ by Eq.(2) using u, u'', and ζ which is a threshold value.

$$\gamma(u,v) = \begin{cases} 1, & R \ge C \;\; or \;\; |u-u''| < \zeta \\ 0, & otherwise \end{cases} \quad (2)$$

When $\gamma(u,v)$ is 1, a similarity of a matching result is high, and the result corresponds uniquely.

4.2 Distinction by disparity

Waterdrops adhere on a protection glass surface. Therefore, disparity of the waterdrops can be calculated from camera parameters and geometrical relation between the protection glass and the camera.

Disparity η is calculated from Eq.(3).

$$\eta = \frac{bf}{l} \quad (3)$$

where f is an image distance (distance between the image plane and the principal point of the lens). Disparity $S(u,v)$ is calculated from a matching result, when $\gamma(u,v)$ is 1, and $S(u,v)$ is compared to disparity η. We set a threshold δ for distinguishing waterdrops. Pixels of $|S(u,v)-\eta| < \delta$ are regarded as waterdrop elements.

In Eq.(4), $\alpha(u,v)$ is the result of waterdrop detection given to each pixel. Pixels of $\alpha(u,v)=1$ are waterdrop elements.

$$\alpha(u,v) = \begin{cases} 1, & \gamma(u,v)=1 \;\; and \;\; |S(u,v)-\eta| < \delta \\ 0, & otherwise \end{cases} \quad (4)$$

5 Image correction

A hidden region by a waterdrop is usually given in other image. Therefore, the method removes waterdrops by replacing the pixel intensities with those in the other image. In order to use the pixel intensities of the other image for a waterdrop removal, the positions corresponding to the waterdrops are required. Therefore, it is necessary to estimate disparities in positions of waterdrops.

5.1 Disparity estimation

The method estimates disparities in positions of waterdrops using an inpainting algorithm [4].

Originally, the inpainting algorithm is a method that corrects the noise of an image in consideration of slopes of image intensities. The inpainting algorithm's merit is fine reproducibility for edges. Its demerit is poor reproducibility for a complicated texture. The proposed method in this paper treats a disparity $S(u,v)$ as a pixel intensity. And it calculates disparities of pixels of $\alpha(u,v)=1$. In many cases disparities do not produce a complicating texture than intensities. Therefore, in many cases it can ignore inpainting algorithm's demerit of poor reproducibility for complicated texture.

5.2 Image correction

The method removes waterdrops after estimation of disparities. A pixel intensity $I(u,v)$ in a waterdrop position is given by the following equation, where $s(u,v)$ is the estimated disparity and $I'(u,v)$ is the pixel intensity of the complementary image in the image pair.

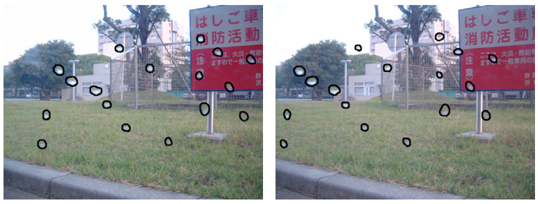
$$I(u,v)=\begin{cases} I'(u-s,v), & (u,v) \text{ is in the left image.} \\ I'(u+s,v), & (u,v) \text{ is in the right image.} \end{cases} \quad (5)$$

6 Experiment

An experiment was made to confirm the validity of the method. The method removes waterdrops that appear in common view of a stereo image pair. Figure 3 shows the experimental images of a scene that consists of objects with a variety of distance. Figure 4 shows positions of waterdrops indicated manually for reference. The image size of Fig.3 is 640x480 pixels. The distance l between the protection glass and cameras was 210mm. The base line length b was 15mm. The disparity η for the protection glass surface calculated using Eq. (3) was 79 pixels. The template size in template matching was 11x11 pixels. The threshold C for a correlation value was 0.4. The threshold ζ that investigates one-to-one correspondence was 5. The threshold δ for waterdrop detection was 10. Figure 5 shows a result of waterdrop position detection. The method detected all waterdrops in both images. However, two spurious detections exist in the right image. Figure 6 shows disparities in the images. Bright pixels have large disparities and dark pixels have small disparities. Black pixels have unknown disparities. Disparities of the black pixels are estimated using an Inpainting algorithm [4]. Figure 7 shows results of waterdrop removal. Figure 8 shows magnified left images of waterdrop removal results. We can confirm the validity of the proposed image correction method for a distant scene and a close range scene. Figure 9 shows another experiment result.

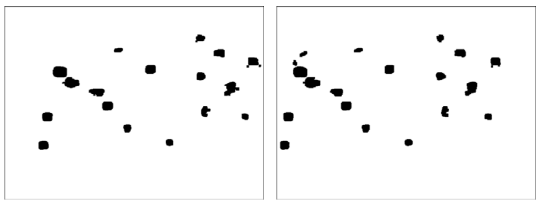
(a) Left image (b) Right image

Fig.3 Parallel stereo images.



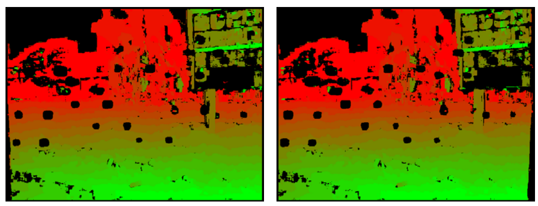
(a) Left image (b) Right image

Fig.4 Waterdrop positions indicated manually.



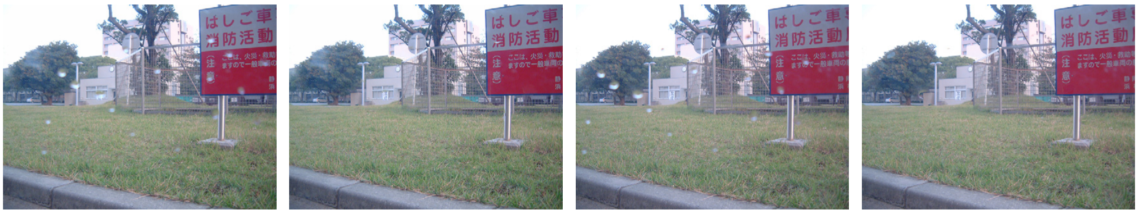
(a) Left image (b) Right image

Fig.5 Results of waterdrop detection.



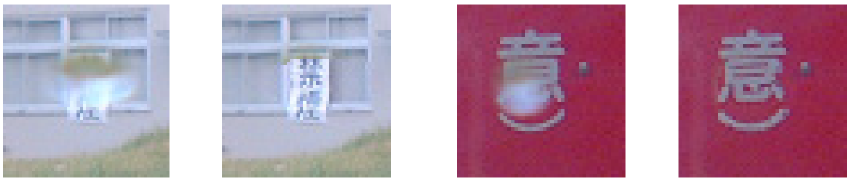
(a) Left image (b) Right image

Fig.6 Disparities in the images.



(a) Left image (original) (b) Left image (result) (c) Right image (original) (d) Right image (result)

Fig.7 Results of waterdrop removal.



(a) Distant scene (b) Resulting image (c) Close range scene (d) Resulting image

Fig.8 Magnified left images of removal result.

(a) Left image (original) (b) Left image (result) (c) Right image (original) (d) Right image (result)

Fig.9 Another experiment result

7 Conclusion

In this paper, we proposed a method for removing waterdrops that disturb a view in stereo images. The method is effective for removal of waterdrops that are difficult to remove by background subtraction or inter-frame difference. The experimental result showed the validity of waterdrop removal for a close-range view stereo image pair that has disparities. As a future work, we should improve the precision of disparity estimation.

Acknowledgment

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