Removal of Waterdrops on a Protection Glass Surface from Parallel Stereo Images

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ABSTRACT

In this paper, we propose a new method for removing waterdrops which, adhering to a protection glass surface in front of cameras, block a scene in the common view of a parallel stereo image pair. The method consists of the following three steps. First, it detects positions of waterdrops in images by comparing disparities measured from stereo images with the value calculated from a geometrical relationship of the glass surface and the cameras. Next, it estimates disparities of image regions hidden by waterdrops, based on the property that disparities are generally similar with those around waterdrops. Finally, it removes waterdrops from images by replacing the above regions with corresponding image regions obtained by disparity referring. An experimental result has shown the validity of the proposed method.

KEY WORDS: Stereo images, Noise removal, Template mathing

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. For example, the lighting condition differs whether it is in the daytime or at night, and whether it is sunny, cloudy or rainy. Especially, it should be noted that, in rainy days, we can not 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. The background subtraction has a disadvantage that it cannot be used in case when the background itself changes. Also, the 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 snow fall. Therefore, 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 of 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 can be used only for distant scenes which have no disparities between different viewpoints. Another is a method that it 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.

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.

In the following, the details are given in a situation where two cameras are set up in parallel and a protection glass surface is also set up in parallel in front of the both cameras (Fig.1).

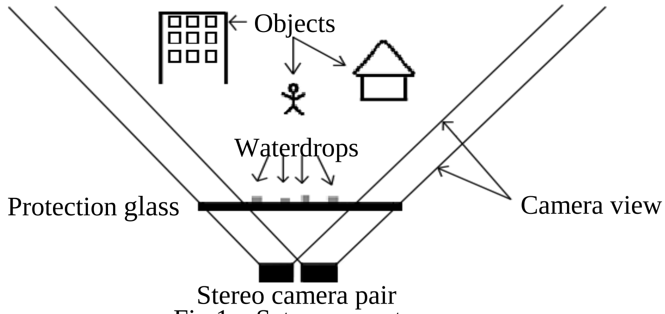


Fig.1 Setup geometry.

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.

Detection by one to one correspondence

The method detects positions of waterdrops using disparities which 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.(1) using u and u'', where ζ is a threshold value.

$$\gamma(u,v) = \begin{cases} 1, & if \;\; R \geq C \;\; or \;\; \left|u - u''\right| < \zeta \\ 0, & otherwise \end{cases} \tag{1}$$

When $\gamma(u,v)$ is 1, a similarity of a matching result is high, and the result corresponds one-on-one. Here, we consider about a case that all values in a template are same. A template matching by normalized cross correlation can not use when all values in a template are same. Therefore, the method gives $\gamma(u,v) = 0$ to pixel of a center of a template, when all values in a template are same.

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.(2), where b, f, and d denote a base-line length, an image distance (distance between the image plane and the principal point of the lens), and a distance between the camera and the protection glass, respectively.

$$\eta = \frac{bf}{d} \tag{2}$$

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 $\left|S(u,v) - \eta\right| < \delta$ are regarded as waterdrop elements.

In Eq.(3), $\alpha(u,v)$ is the result of waterdrop detection given to each pixel. Pixels of $\alpha(u,v) = 1$ are waterdrop elements.

$$\alpha(u,v) = \begin{cases} 1, & if \ \ \gamma(u,v) = 1 \ \ and \ \ |S(u,v) - \eta| < \delta \\ 0, & otherwise \end{cases} \quad (3)$$

Image correction

Waterdrops are removed after detecting waterdrop positions. A hidden region by a waterdrop is 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. If the disparities of waterdrop positions are determined, the method can find pixels corresponding to the waterdrop positions.

Disparity estimation

The method estimates disparities in positions of waterdrops using an inpainting algorithm [4]. Originally, the inpainting algorithm is a method which 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 become a complicating texture than intensities. Therefore, in many cases it can ignore inpainting algorithm’s demerit of poor reproducibility for complicated texture.

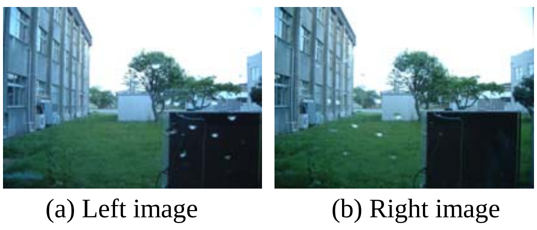
Image correction

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.

$$I(u,v) = \begin{cases} I'(u-s,v), & if \quad (u,v) \text{ is in the left image.} \\ I'(u+s,v), & if \quad (u,v) \text{ is in the right image.} \end{cases} \quad (4)$$

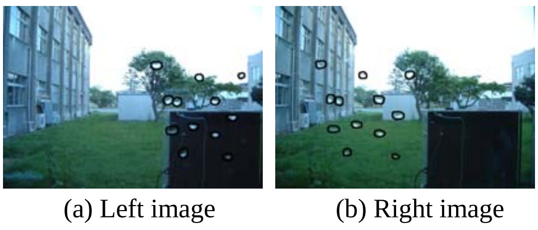
Experiment

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 2 shows the experimented images of a comparatively close scene having disparities. Figure 3 shows positions of waterdrops indicated manually. The image size of Fig.2 is 640x480 pixels. The distance f between the image and the principal point of the lens is 715 in pixel unit. The distance d between the protection glass and cameras is 220mm. The base line length b is 80mm. The disparity η for the protection glass surface calculated using Eq. (1) is 260 pixels. The template size in template matching is 15x15 pixels. The threshold C for a correlation value is 0.4. The threshold ζ which investigates one-on-one correspondence is 5. The threshold δ for waterdrop detection is 10. Figure 4 shows a result of waterdrop position detection. In the left image, the method detected nine waterdrops correctly. However, three waterdrops were not detected, and an incorrect detection exists, too. In the right image, the method detected correctly ten waterdrops. However, two waterdrops were not detected. Figure 5 shows results of waterdrop removal. Figure 6 shows magnified images of waterdrop removal results. The main cause of waterdrop detection failure is that the template matching is not able to obtain right congruent points. Accuracy of waterdrop detection will be improved by increasing the precision of the template matching.



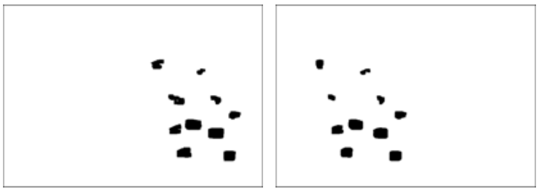
(a) Left image (b) Right image

Fig.2 Parallel stereo images.



(a) Left image (b) Right image

Fig.3 Waterdrop positions indicated manually.

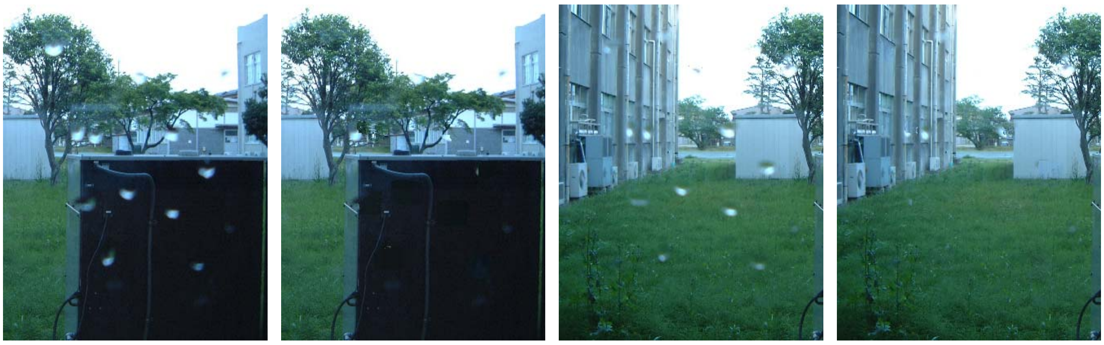


(a) Left image (b) Right image

Fig.4 Results of waterdrop detection.

(a) Left image (b) Right image

Fig.5 Results of waterdrop removal.



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

Fig.6 Magnified images of removal result.

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 validities of waterdrop removal for a close-range view stereo image pair that has disparities. As a future work, we should improve the precision of template matching.

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