MVA2005 IAPR Conference on Machine VIsion Applications, May 16-18, 2005 Tsukuba Science City, Japan
3-34

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

Yuu Tanaka, Atsushi Yamashita, Toru Kaneko, and Kenjiro T.Miura
Shizuoka University
3-5-1 Johoku, Hamamatsu-shi, Shizuoka 432-8561, Japan
{f0330051, tayamas, tmtkane, tmkmiur}@ipc.shizuoka.ac.jp

## Abstract

*In this paper, we propose a method for restoration of images stained with waterdrops on a protection glass surface. The method 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.*

## 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 of inapplicability to cases where the background itself changes. Also, inter-frame difference cannot detect stationary objects after they have appeared and stay in the image. A noise elimination method based on median filtering in temporal sequence has been proposed [1]. It is valid for removal of moving noise such as snow fall. For the above-mentioned methods, it is difficult for these methods to detect waterdrops on the protection glass surface since waterdrops stay without motion in the image.

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 when a background changes. However, since it is based on the difference between images, it cannot be used for close scenes which have disparities between different viewpoints. Another is a method that removes waterdrops using multiple images from a motion camera [3], but this method cannot be used when a background contains moving objects.

In this paper, we propose a method for removing waterdrops where the problem of a close range scene in [2] is resolved by using stereo vision, i.e, the proposed method in this paper is valid for close scenes.

## 2 Method Outline

The method employs a stereo camera system where two cameras are set behind a single protection glass plane (Fig.1). It 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.

The method consists of the following three procedures.

(a) It acquires a stereo image pair.

(b) It executes template matching between luminance components of the image pair. Waterdrops are distinguished by using disparities of pixels.

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

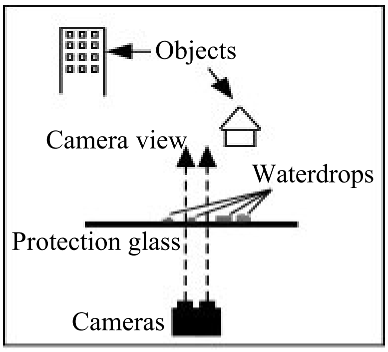



Fig.1 System setup.

## 3 Baseline Length Constraint

The proposed method detects a waterdrop in one image and and replaces it with a corresponding scene that is not blocked by the waterdrop in the other image.

This leads to a requirement that the baseline length needs to satisfy the following relation

$$b > \frac{z\rho}{z-l} \tag{1}$$

where $b$, $l$, $z$ and $\rho$ denote the baseline length, the distance between cameras and the protection glass, the distance between the cameras and the object nearest to the cameras, and a waterdrop size, respectively (see Fig.2).

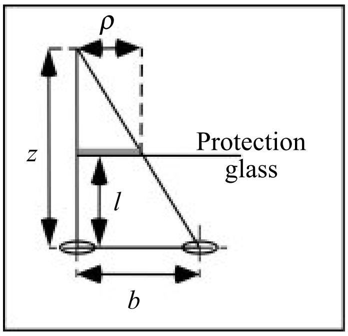


Fig.2 Baseline length constraint.

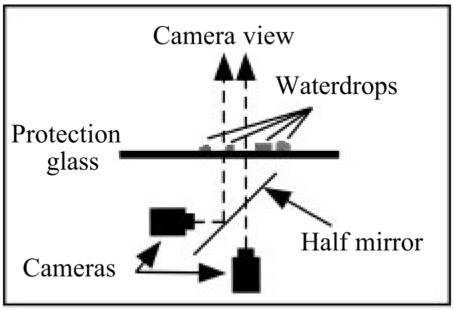


Fig.3 A configuration using a half mirror.

The waterdrop size $\rho$ has a physical maximum limit $\rho_{\max}$, then 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 ordinaly stereo camera configuration. Figure 3 shows an example of configuration using a half mirror to solve this problem.

## 4 Detection of Waterdrop Positions

The method detects positions of waterdrops using disparities which are obtained by template matching of stereo images.

Waterdrops adhere to a protection glass surface. Therefore, disparity of the waterdrops is definitely given from camera parameters and geometrical relation between the protection glass and the camera.

Disparity $\eta$ is calculated from the following equation

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

where $f$ is an image distance (distance between the image plane and the lens center). Disparity $S(u,v)$ calculated from the matching result is compared with disparity $\eta$. Pixels satisfying the following equation are regarded as waterdrop elements, where $\delta$ is a threshold.

$$\left|S(u,v) - \eta\right| < \delta \tag{3}$$

## 5 Image Correction

A scene hidden by a waterdrop in one image is usually given in the other image except for occlusion. Therefore, the method removes waterdrops by replacing the pixel values with those in the other image. In order to use the pixel values in the other image for a waterdrop removal, their positions corresponding to the waterdrops are required. This can be realized by estimating disparities of a scene hidden by waterdrops.

### 5.1 Disparity estimation

The method estimates disparities of a scene hidden by waterdrops by using an image inpainting algorithm [4]. This algorithm is a method for reproduction of damaged images. The basic idea of the algorithm is to smoothly propagate information from the surrounding areas in the isophotes direction. Its problem is poor reproducibility for complicated textures. Our method treats a disparity $S(u,v)$ as a pixel intensity, and disparities usually have less complicated textures than intensities. Therefore, in many cases we can ignore the above problem of the image inpainting algorithm.

### 5.2 Pixel intensity substitution

The method removes pixels regarded as waterdrops from one image, and covers with the pixel values which are obtained from the other image by using estimated 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.

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

In the case of color images, Eq.(4) is applied to individual color components. If there exist differences in sensitivity or exposure between two cameras, $I'(u,v)$ in Eq.(4) should be corrected by comparing values of pixels surrounding waterdrops in both images.

## 6 Experiment

An experiment was made to confirm the validity of the method. In the experiment, a single CCD camera was translated parallel to the protection glass plane to form a stereo camera system instead of using two cameras and a half mirror. The baseline length $b$ was 15mm. The distance $l$ between the protection glass and cameras was 210mm. The image size was 640x480 pixels. The disparity $\eta$ for the protection glass surface calculated using Eq. (3) was 79 pixels. Normalized cross correlation was used for template matching. The template size was 11x11 pixels. The threshold $\delta$ for waterdrop detection in Eq.(3) was 10. Figure 4 shows experimental images of a scene that consists of objects with a variety of distances. Figure 5 shows positions of waterdrops indicated manually for reference.

Figure 6 shows results of waterdrop position detection. The method removes waterdrops that appear in common view of a stereo image pair. About 90% of pixels belonging to waterdrops were detected in both image left and right.

Figure 7 shows disparities in the images of common view. Bright pixels have large disparities and dark pixels have small disparities. Black pixels have unknown disparities. Figure 8 shows the result of disparity estimation using the image inpainting algorithm. Figure 9 shows the result of waterdrop removal. Figure 10 shows magnified left images of waterdrop removal result. We can confirm the validity of the proposed image correction method for a close range scene as well as a distant scene. Figure 11 shows 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. Experimental results 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.

## References


[1] H.Hase, K.Miyake and M.Yoneda: "Real-time Snowfall Noise Elimination", *Proceedings of the 1999 IEEE International Conference on Image Processing*, Vol.2, pp.406-409, 1999.

[2] A.Yamashita, M.Kuramoto, T.Kaneko and K.T.Miura: "A Virtual Wiper - Restoration of Deteriorated Images by Using Multiple Cameras -", *Proceedings of the 2003 IEEE/RSJ International Conference on Intelligent Robots and Systems*, pp.3126-3131, 2003.

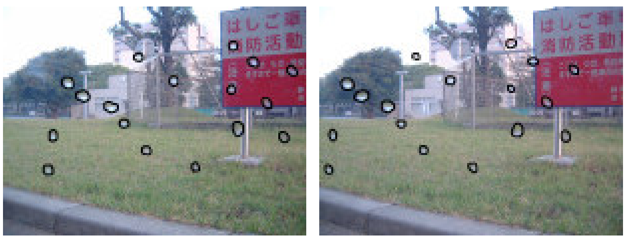
[3] A.Yamashita, T.Kaneko and K.T.Miura: "A Virtual Wiper - Restoration of Deteriorated Images by Using a Pan-Tilt Camera -", *Proceedings of the 2004 IEEE International Conference on Robotics and Automation*, pp.4724-4729, 2004.

[4] M.Bertalmio, G.Sapiro, V.Caselles and C.Ballester: "Image Inpainting", *Proceedings of SIGGRAPH2000*, pp.417-424, 2000.



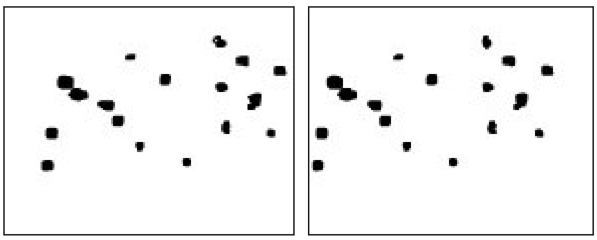
(a) Left image (b) Right image

Fig.4 Experimental stereo images.



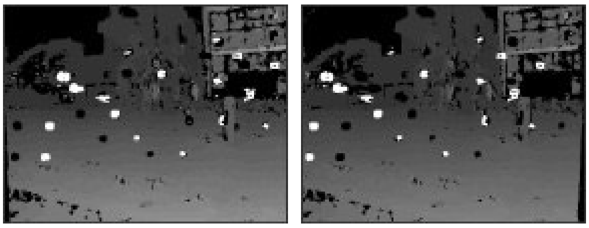
(a) Left image (b) Right image

Fig.5 Waterdrop positions indicated manually.



(a) Left image (b) Right image

Fig.6 Result of waterdrop detection.



(a) Left image (b) Right image

Fig.7 Disparities in the images.

(a) Left image (b) Right image

Fig.8 Result of disparity estimation.


(a) Left image (b) Right image

Fig.9 Result of waterdrop removal.

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

Fig.10 Magnified left images of removal result.

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

Fig.11 Another experiment result.