MVA2002 IAPR Workshop on Machine Vision Applications, Dec. 11-13, 2002, Nara-ken New Public Hall, Nara, Japan

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Removal of Adherent Waterdrops in Images by Using Multiple Cameras

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Abstract

In this paper, we propose a new method for the removal of view-disturbing waterdrops from images taken with multiple cameras. In rainy days, it is often the case that scenes taken by the camera are hard to see because of adherent waterdrops on the surface of the lens protecting glass. The proposed method analyses multiple camera images describing the same scene, and synthesizes an image in which adherent waterdrops are eliminated.

1 Introduction

In rainy days, it is often the case that scenes taken by the camera are hard to see because of adherent waterdrops on the surface of the lens protecting glass. Therefore, it would be desirable to remove such waterdrorps from images of such scenes. This issue can be regarded as a noise removal problem. There are a lot of studies that detect a moving image noise [1]. These techniques remove the moving noise by taking the difference between the initial background scene and a current scene, or taking the difference between temporarily adjacent two frames. However, it is difficult to apply these techniques to the above problem, because waterdrops are stationary noises in this case. On the other hand, the image restoration technique for damaged and occluded images is also proposed [2]. However, applying this method requires to indicate the region of waterdrops interactively.

To solve the problem, we have proposed a method using two cameras, where a new image without waterdrops is synthesized from two images describing the same scene [3]. However, this method is only effective for scenes in which a small number of waterdrops exist, and waterdrops cannot be removed when waterdrops occupy the same positions of the image pair.

In this paper, we propose a new method for the removal of view-disturbing waterdrops from images taken with multiple cameras. The simplest method to apply is to adopt a majority decision rule. However, this method cannot remove waterdrops in the case that waterdrops are at the same position of two or more images (Fig.1). Our method realizes the discrimination of waterdrops by incorporating a technique of removing waterdrops by using image pairs into a decision rule. This paper focuses on algorithms for extracting waterdrops from trinocular images of a distant scene, in which no stereoscopic disparities exist.

2 Removal of waterdrops

The difference between two images is small where

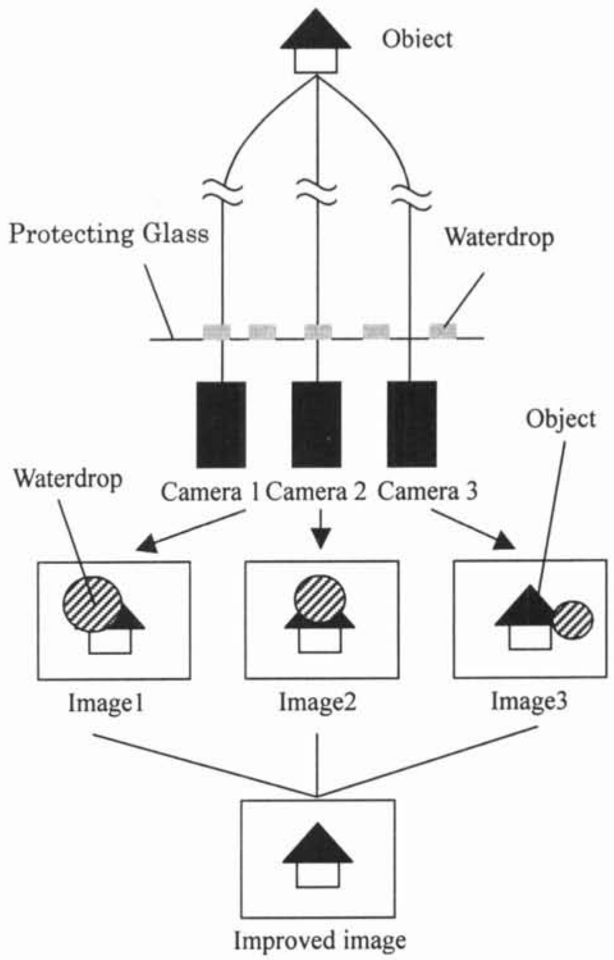

Fig. 1 Overview of the proposed method.

waterdrops do not exist, and it is large where waterdrops exist. The region of the waterdrops can be extracted by using the difference between two images. This region itself, however, does not have information in which image waterdrops exist. This section describes the proposed procedure for removing waterdrops. The algorithm consists of three steps as follows.

(1) Image registration
(2) Extraction of waterdrop candidate regions
(3) Waterdrops removal

2-1 Image registration

At the first step, three images of a scene are acquired simultaneously by using three cameras. Let Image1, Image2, and Image3 be the acquired images from three cameras. Since it is very important for the removal of waterdrops to take the exact difference between image pairs, a positional and chromatic registration is needed. In the following, let us

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regard Image2 as a reference image. Then the positions and RGB values of Image1 and Image3 are to be modified to fit those of Image2. The positional registration is achieved by minimizing the total sum of difference between two images. The chromatic registration is achieved by matching the averages of RGB values of Image1, 3 with those of Image2, respectively.

2-2 Extraction of waterdrop candidate regions

At the second step, the position where waterdrops exist is estimated by comparing two images. Here, it should be noted that we use monochromatic gray-scale images converted from the color images obtained above. We define regions where the differences between two gray-scale images are larger than a threshold as the waterdrop candidate regions of two images. The difference between two images is calculated, and thresholding gives a difference image where waterdrop candidate regions and the rest are represented binarily. The difference image $g_{ij}(x,y)$ is obtained by

$$g_{ij}(x,y)=\begin{cases}0 & \left|f_i(x,y)-f_j(x,y)\right|\le L\\ 1 & \left|f_i(x,y)-f_j(x,y)\right|>L\end{cases}, \qquad (1)$$

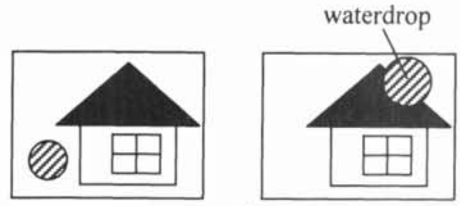
where i, j $(=1,2,3)$ are image numbers, $f_i(x,y)$ is the pixel value of the i-th gray-scale image value at (x,y), and L is a threshold. The region of $g_{ij}(x,y)=1$ is defined as waterdrop candidate region. Hereafter, we call the difference image as WCR image (Fig.2).

The threshold should be determined for each waterdrop candidate region independently, because its optimum value differs from each other. If the threshold is too high, the size of waterdrop candidate region becomes smaller than the actual size, or the waterdrop candidate region vanishes (Fig.3 (a)). If the threshold is too low, the size of waterdrop candidate region becomes larger than the actual size, and many noises appear as false waterdrop candidate regions (Fig.3 (b)). Therefore, it is necessary to determine the appropriate threshold automatically for each waterdrop candidate region (Fig.3 (c)). A method for determining the appropriate threshold is shown in the following.

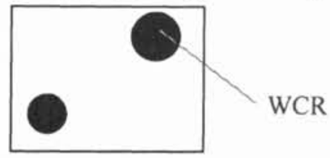
The thresholding method is based on the property that a waterdrop has an edge contour against the background image and that a variance of pixel values along this contour is large compared to that along inner contours within a waterdrop. In our method, the variance at a contour pixel is given by the sum of squared values of the difference between each pixel within the 3×3 pixel window around the contour pixel and the mean value in the gray-scale image $f(x,y)$. Then we calculate the average variance A_{kl} along the pixels belonging to one contour, by the following equation.

$$A_{kl}=\sum_{n=1}^{N_l}V_{kl}(n)\Big/N_l\ , \qquad (2)$$

where k is an image number, l is a label number for each waterdrop candidate region, $V_{kl}(n)$ is the variance at n-th contour pixel of l-th region, and N_l is the number of pixels belonging to the contour. Finding an appropriate threshold for each region is realized as follows.



(a) Gray-scale image1. (b) Gray-scale image2.



(c) WCR image.

Fig.2 WCR (waterdrop candidate region) image.

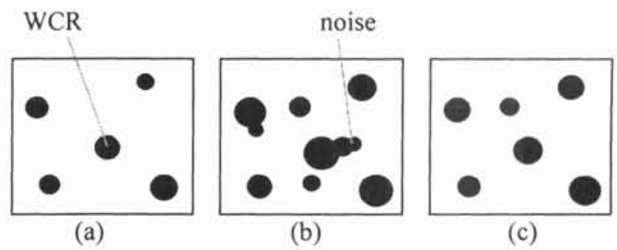


Fig.3 The waterdrop candidate regions in WCR image: (a) Higher threshold. (b) Lower threshold. (c) Appropriate threshold.

First, threshold L is initialized with the value large enough not to overestimate the waterdrop candidate region, and A_{kl} is calculated. Then, threshold L is lessened step by step to a given lowest value, and A_{kl} is calculated in each step. If a new region appears by lowering the threshold, a new label is given to the region. After the iteration, we obtain the average variances A_{1l}, A_{2l}, A_{3l} of three gray-scale images for l-th waterdrop candidate region, and the threshold that gives the maximum value of these variances is regarded as the appropriate threshold.

2-3 Waterdrop removal

WCR images themselves have no information in which image waterdrops exist. Waterdrops are distinguished by combining the information of three WCR images and the feature values of three gray-scale images.

To find pixels not belonging to waterdrops, we define the following value,

$$h(x,y)=g_{12}(x,y)+g_{23}(x,y)+g_{31}(x,y). \qquad (3)$$

The value of $h(x,y)$ varies as 0, 1, 2, 3, and when $h(x,y)$ = 0, 1 and 2, the distinction is realized by pixel-based processing.

<u>Case1:</u> $h(x,y)=0$

Waterdrops do not exist in any of three images. Then we use Image2 that is defined as the reference image.

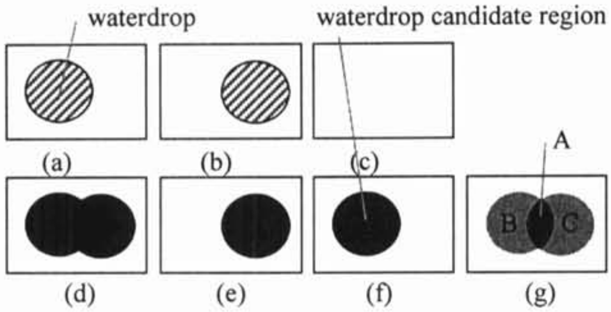


Fig.4 WCR images and SWCR image in Case4-1:
(a) Original image1. (b) Original image2. (c) Original image3. (d) WCR image $g_{12}(x,y)$ (e) WCR image $g_{23}(x,y)$ (f) WCR image $g_{31}(x,y)$ (g) SWCR image $h(x,y)$. In WCR image, 0/1-pixel is shown in white/black. In SWCR image, 0/2/3-pixel is shown in white/gray/black.

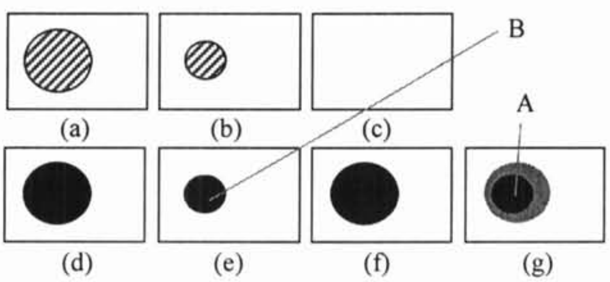


Fig.5 WCR images and SWCR image in Case4-2:
(a)-(g): The same as those in Fig.4.

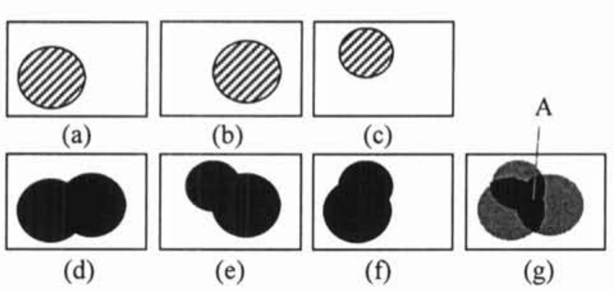


Fig.6 WCR images and SWCR image in Case4-3:
(a)-(g): The same as those in Fig.4.

Case2: $h(x,y)=1$
When $g_{12}(x,y)$ = 1, the pixel in Image1 or Image2 belongs to a waterdrop. Then Image3 is used as a waterdrop free image. In the same way, Image1 and Image2 are used when $g_{23}(x,y)=1$ and $g_{31}(x,y)=1$, respectively.

Case3: $h(x,y)=2$:
A waterdrop exists only in one image of the three. When $g_{12}(x,y)$ = 0, the pixels in Image1 and Image2 do not belong to a waterdrop, then we use Image2. Similarly, when $g_{23}(x,y)=0$, Image2 is used. When $g_{31}(x,y)=0$, either Image1 or Image3 can be used.

Case4: $h(x,y)=3$:
In this case, it is impossible to distinguish which pixel among three images belongs to a waterdrop by pixel-based processing. The distinction is realized by the following region-based one. Here, we have three subcases shown in Fig.4, Fig5, and Fig6. In figures, SWCR images are refered as images of the sum of waterdrop candidate region images.

Case4-1: The region satisfying $h(x,y)=3$ (A in Fig.4 (g)) is surrounded by the two regions satisfying $h(x,y)=2$ (B and C Fig.4 (g)). The surrounding regions determine in which image a waterdrop exists. Since the region satisfying $h(x,y)$ = 3 belongs to a waterdrop of the surrounding regions, we use the image in which the waterdrop of the two surrounding regions does not exist.

Case4-2: The region satisfying $h(x,y)=3$ (A in Fig.5 (g)) coincides with one of the waterdrop candidate region (B in Fig.5 (e)). The region satisfying $h(x,y)=3$ in either of two images belongs to a waterdrop. The image with the smaller A_{kl} is used as a waterdrop-free image.

Case4-3: The regions in three images corresponding to the region satisfying $h(x,y)=3$ (A in Fig.6 (g)) contain pixels belonging and not belonging to a waterdrop. We find the latter pixels by minority decision, because two images have a waterdrop in the corresponding regions. The former pixels belong to a waterdrop in three images simultaneously and it is impossible to obtain a waterdrop free image.

3 Experimental Results

Original images 1,2, and 3 (512×480 pixel) are shown in Fig.7. The range of gray-scale pixel values was 0-255. The initial value of threshold L was 20, and its lowest limit was 6. The average occupation rate of waterdrops in these images to all area is 12.3%.

A result with the proposed method is shown in Fig.8. The method gives a clearer image than original ones. A result with a simple majority decision method is shown in Fig.9 for a comparison. The proposed method gives a better result than a simple majority decision method. The occupation rates of the waterdrops to all area are 1.7% with the proposed method, and 2.5% with the simple majority decision method, respectively. However, when the waterdrops exists in the same place of three images, it is impossible to remove the waterdrops from images.

4 Conclusions

In this paper, we proposed an effective method for the removal of view-disturbing waterdrops adherent to the lens protecting glass of a camera. The method is applied to three camera images of a distant scene, in which no stereoscopic disparities exist. Discrimination of waterdrops is realized by incorporating the result obtained from the difference of images and the variance of pixel values along a waterdrop edge contour into a decision rule. Results of a preliminary experiment have shown the effectiveness of the proposed method.

References

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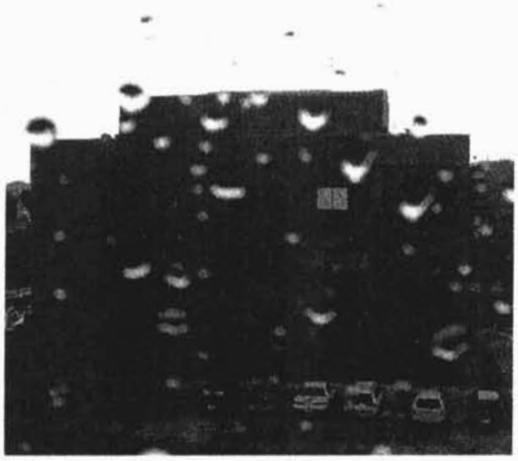

(a) Original image 1.

(b) Original image 2.

(b) Original image 3.

Fig.7 Original images.

Fig.8 A result with the proposed method.

Fig.9 A result with a simple majority decision method.

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