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Removal of Glare Caused by Water Droplets

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Figure 1: Our technique detects and removes glare caused by water

Abstract

Removal of view disturbing noise from an image obtained with a camera under adverse weather conditions is important. In this paper, we present a method of removing glare caused by water droplets, or other foreign objects, adhering to an imaging lens or its protective glass. We have designed and implemented an electronically controlled optical shutter array that detects and removes glare. Our system can easily be used with unmodified, commercially available digital cameras and lenses. We also present the possibility of applying this technique for the removal of general glare caused by the imaging lens itself.

Keywords: Computational Photography,Coded Imaging, Image statistics, Glare, Image Processing, Optical Shutter

1 Introduction

Removal of view disturbing noise is important for a variety of fields like surveillance or television broadcasting. Glare is one of the view disturbing noises and is defined as difficulty seeing in the presence of bright light sources such as sunlight or stadium lighting (see Fig. 2(a)). In optical systems, general glare is a result of scattering light over multiple paths inside the camera body and lens optics. Water droplets, adhering to an imaging lens or its protective glass, also cause glare (see Fig. 2(b)). In this case, scattering is occurring inside the water droplets, imaging lens and camera body.

A lens hood or low reflection coated lens is used to reduce general glare. Lens hoods block the bright light from outside of the field of view, and a low reflection coated lens reduces scattering occurring inside the lens. However, a lens hood does not work when the bright light source is inside the field of view, and low reflection coated lenses are expensive.

As for removing glare computationally, several effective methods have been proposed[5-14]. However, most of the computational image generation methods often make additional artifaces or require some human intervention with

(a) (b)

Figure 2: The visual appearances of glare. (a) Imaging lens and sunlight cause glare. (b) Water droplets adhere to an imaging lens and cause glare with artificial lights. The shape of the glare reflects the shape of the camera aperture.

camera. Therefore it is still difficult to remove glare perfectly using computationally method.

Removal of water droplets physically is might be the most effective way to reduce glare. Water-repellent treatments or wiper blades are used for this, but those cannot perfectly remove the These methods are effective water droplets.

In this paper, we present a method of removing glare to block scattering light caused by water droplets using optical shutter array that can control light transmission. We insert an optical shutter array in front of the camera lens. By turning on and off each optical shutter element in turn, we get several images. From those images, our method automatically detects the image that includes scattering light. Accordingly we know the position of water droplets. By turning off the optical shutter array element that corresponds to the position of water droplets, the scattering light cannot reach to the image sensor. Therefore we remove a glare.

In this paper, we present a fundamental principle of our method, framework of our trial camera system that can remove glare, and experimental result that show the efficiency of our method.

2 Related Work

Removing the effects from bad conditions such as rain, snow, fog, mist has been discussed in the computer vision field. The work of Nayar and Narashimhan [1] in handling problems posed by bad weather has summarized existing models in

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atmospheric optics. Garg and Nayar [2] describe a photometric model of rain droplets. Garg and Nayar [3] detect and remove rain from video.Improving the optical elements of a camera is good way to reduce glare. The low reflection coating lens reduces scattering inside the imaging lens and reduces glare. Boynton and Kelley [4] developed a liquid-filled camera that reduces the internal scattering of light. As for removing glare computationally, several methods have been proposed. Deconvolution methods have been used to remove glare in the medical field by Faulkner et al. [5] and the field of astronomy by Starck et al. [6]. In HDR photography, glare removal is discussed by Reinhard et al. [7]. Computational photography is a new field created by the convergence of image processing, computer vision and photography. It adds new features to the traditional camera using computational techniques. Nayar et al. [8][9] developed the notion of a programmable imaging system. They inserted digital micro-mirror device (DMD) into the camera. This system can be used to implement a wide variety of imaging functions, including, high dynamic range imaging, feature detection and object recognition. Zomet and Nayar [10] developed a lensless camera that uses a controllable aperture instead of an imaging lens. Nayar and Branzoi [11] describe methods to enhance the dynamic range of a camera using a LCD panel in front of a camera. Ashok et al. [12] developed a coded aperture camera. They use a coded aperture for refocusing the scene. Talvala et al. [13] present computational photography techniques to remove veiling glare. They use a structured occlusion mask to separate direct and indirect light transport. However, their techniques can not address glare caused by water droplets. Raskar et al. [14] developed a technique that can emphasize or reduce glare. They use a mask placed in front of the imaging sensor to use a 4D analysis of glare inside the camera. Their setup requires only a single-exposure photo. However, their method requires conversion of the camera body and needs high processing power for 4D analysis.We believe that our technique is the first method to address glare caused by water droplets. Our method requires only put optical shutter array in front of camera lens. Thus, our method can use for conventional camera without modification. Our technique is very simple, low-cost and practical.

3 Mechanisms of glare caused by water droplets

In a conventional camera, the standard laws of geometric optics explain image formation as shown in Fig. 3(a). Light rays emitted from point A on the subject surface are refracted by the imaging lens and converge to a point B on the image sensor. Thus we get an image. When there are view-disturbing objects such as water droplets on the lens, rays from light sources are additionally scattered by the objects, imaging lens and camera body elements and then reaches to image sensor. This phenomenon causes glare (see Fig. 3(b)). In this case, light rays from point A are also scattered by water droplet and reaches several points of the image sensor. Thus the droplet also causes blur and distortion (see Fig. 3(c)). Such blur and distortion effect is weak because only a small quantity of light rays scattered by the water droplet reach the image sensor. However, glare appears when there is a bright light source in the scene (see Fig. 4).

On the other hand, we can still get an image even if an opaque obstacle is attached to the imaging lens, because the remaining lens surface, which is not covered by the obstacle, still transports light rays (see Fig. 3(d)).

This means that we can remove glare by blocking the light rays scattered by water droplets. For blocking them, we employ an optical shutter in front of lens, which can select shutting area on the lens. Therefore, we need to detect the position of the water droplets on the lens so that we can selectively block the light rays scatted by the droplets.

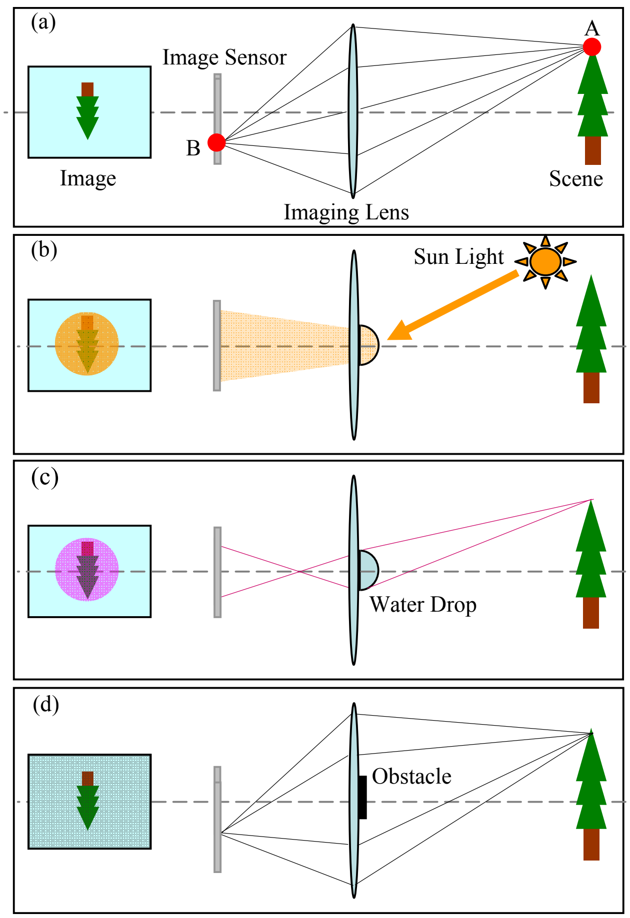


Figure 3: Conceptual schematic (not drawn to scale) of our image formation model. (a) Conventional camera model. Ray of light from point A on the subject surface is refracted by the imaging lens and reaches to a point B on the image sensor. (b) When there is a water droplet on the imaging lens, sunlight is refracted and diffused by water droplet, lens and camera body elements, and, when it reaches the image sensor, it may cause glare. (c) Ray of light from point A is also refracted and diffused, and it may cause blur or distortion. (d) Even if an opaque obstacle is attached to imaging lens, we can get an image. In this case the image mav become dark.

(a) (b)

Figure 4: The visual appearances of glare. (a) With diffused lighting, the blur and distortion effect is limited because only a small quantity of light scattered by water droplets reaches the image sensor. (b) However, when there is a bright light source (in this case, it is a flashlight), glare appears.

4 Detect and Remove Glare

4.1 Detect Water Droplet Position

We use optical shutter array to detect water drop position that adhering to an imaging lens or protective glass. By turning on and off each optical shutter element in turn, we get several images. When there is no water droplet in front of opened shutter element, we get a relatively dark image (see Fig. 5(b)(c)(e)(f)). However, when there is a water droplet in front of an opened shutter element, we get the relatively bright image because of scattered light caused by the water droplet (see Fig. 5(d)). In comparing each image, we find the positions of water droplets.

To detect bright image that affected water droplets, we convert the image to grayscale and then calculate a standard deviation s of image brightness. Standard deviation s is given as below:

$$\boldsymbol{s} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - \boldsymbol{m})^2} \qquad \text{---------(1)}$$

Where n is the number of pixels, x is the brightness of a pixel, the m is mean of the image brightness given as below,

$$\boldsymbol{m} = \frac{1}{n}\sum_{i=1}^{n}(x_i) \qquad \text{---------(2)}$$

If standard deviation s and mean m are large, that image may have a bright area. If s and m are low, that image may not have a bright area. We calculate the each picture's standard deviation s and mean m. Then, we determine threshold st and mt to detect the bright image that is affected by water droplet. We use Otsu's method [15] to determine the threshold. Otsu's method assumes that the image to be thresholded contains two classes of pixels then calculates the optimum threshold separating those two classes so that their combined spread is minimal. When s and mean m is higher than threshold st and mt,we consider that image is affected by water droplet. Therefore, we detect water droplet position.

Fig. 6 shows experimental result of detecting water droplet

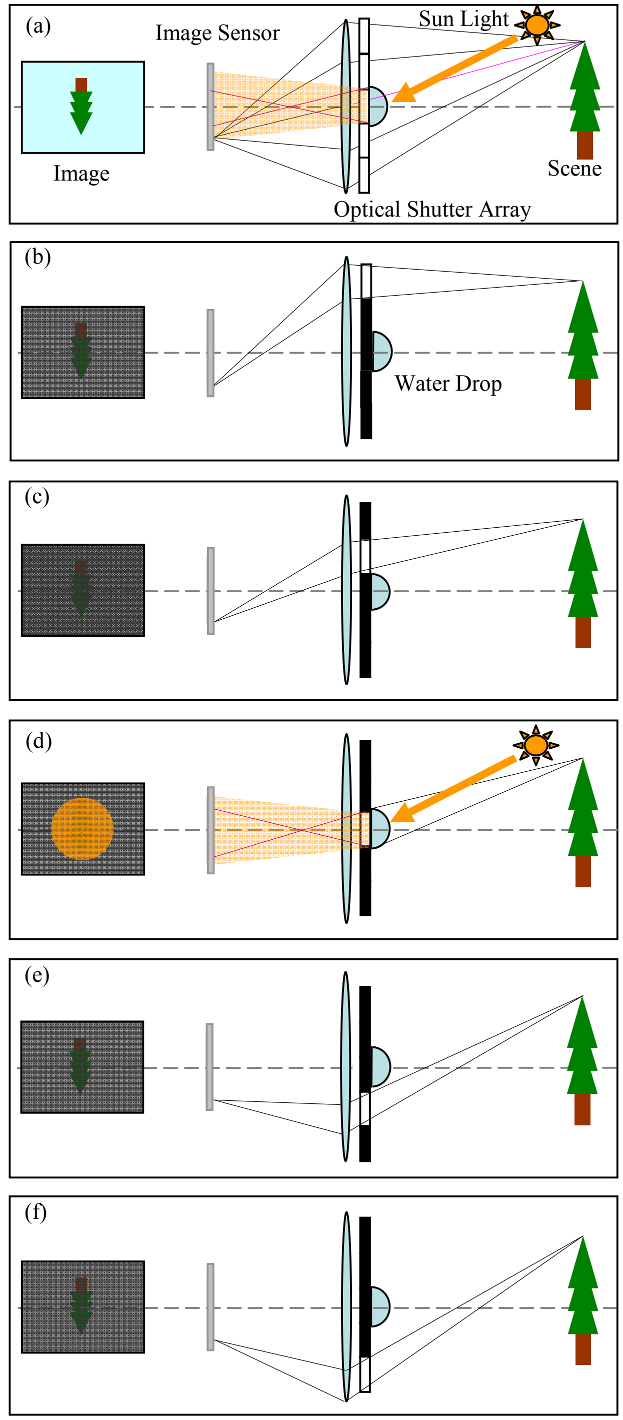


Figure 5: Process for detecting glare. (a) We place an optical shutter array in front of an imaging lens. Opening and closing each optical shutter element in turn detects glare area. (b)(c)(e)(f) When there is no water droplet in front of each shutter elements, we get darker images. (d) When there is water droplet in front of an optical shutter element, we get an image that has a bright area. Thus we know the position of the water droplet.

position. We put a water droplet in front of the optical shutter array at No.45 and No.55 (see Fig. 6(a)). Then we took pictures, turning on and off each optical shutter array element. Our optical shutter array is a 10x10 grid of square liquid-crystal cells, thus we have 100 pictures (see Fig. 6(b)). Figs. 6(c) and (d) are pictures that include scattering light caused by a water droplet in front of the optical shutter array at No.45 and No.55. Fig. 6(e) is a picture of the optical shutter array at No. 56 that has no scattering light. Figs. 6(f) and (g) are plots of the standard deviation s and mean m of each picture's brightness and threshold st and mt. This result shows our method successfully detects water droplet position.

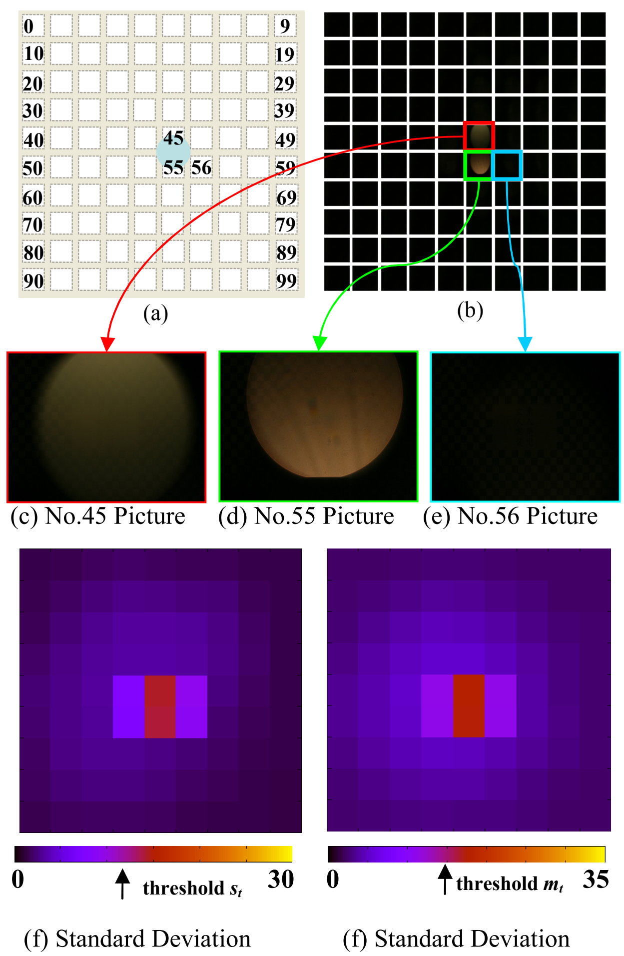


Figure 6: Experimental result of detecting glare. (a) We put a water droplet on the shutter array at No.45 and 55. (b) The pictures of each optical shutter array. (c)(d) The picture includes glare. (e) The picture does not include glare. (f)(g) Plots of standard deviation and mean value of image brightness.

4.2 Removing Glare

We also use optical shutter array to block scattering light caused by water drop that adhering to an imaging lens or protective glass. By turning off the optical shutter array elements that correspond to the position of water droplets, the light rays cannot reach to the image sensor. Therefore we get a clear image (see Fig.7).

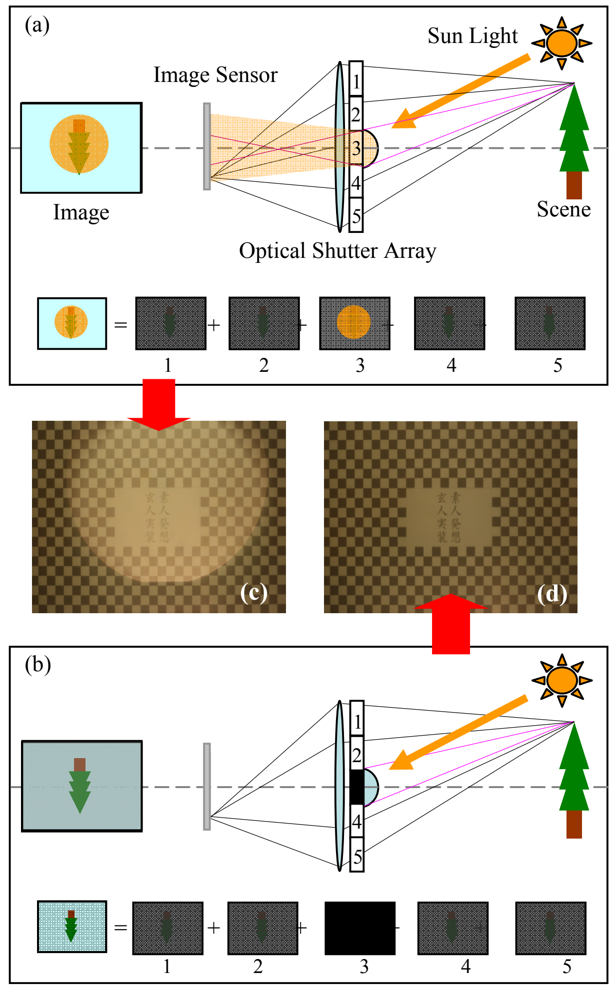
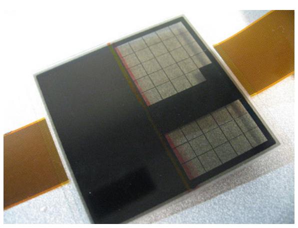
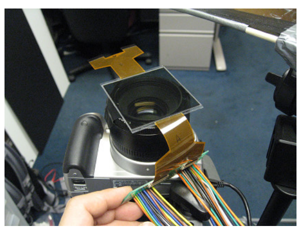


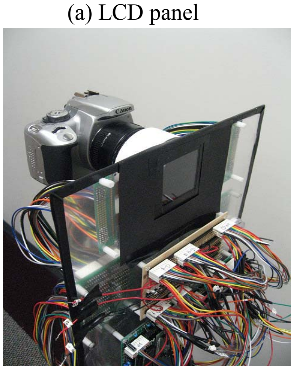
Figure 7: Process of removing glare. (a) Taking a picture with all optical shutter array elements open, we get an image that has glare. (b) By closing the optical shutter element that the water droplet on it, glare does not reach the image sensor. Thus we get a non-glare image. (c) We put a water droplet on the shutter array at No.45 and 55, then glare appeared. (d) Experimental result of removing glare. Glare was removed by closing optical shutter array elements No.45 and 55 that have the water droplet.

5 System Design

We developed glare removing system using optical shutter array to detect position of water droplet that adhering to the imaging lens and block scattering light caused by water droplets (see Fig.8). We use a LCD panel as an Optical Shutter array (see Fig. 8(a)). We developed a 10x10 grid square liquid crystal cell normally white LCD panel. Normally white means that the liquid crystal cells remain transparent until the voltage is removed. The size of each liquid crystal cell is 5x5mm in consideration of water droplets size. We also decide the size of LCD panel 60 x 60mm in consideration of conventional SLR Digital Camera. Our entire system includes Optical Shutter Array, Optical Shutter Array Driver, Camera and PC. The optical system can be placed in front of the camera lens or protective glass without modification. Optical Shutter Array Driver Unit has the capability to control the LCD panel and communicate with the PC. We use a 10.1MP Canon EOS Digital Rebel XTi digital SLR camera body and Canon EF 50mm F=1.8 lens. The entire system is controlled by PC software.
Our system does not require any calibration procedure. We do not need to have any information about the geometry between the camera and the LCD panel for removing the glare, but simply need to capture images taken with the different positions of LCD elements, because our method can automatically detects the water droplet's position.


(a) LCD panel


(b) LCD panel on lens


(c) Entire System (front)


(d) Entire System (back)

Figure 8: Our system can be easily used with unmodified, commercially available digital cameras and lenses.

6 Experimental Results

The proposed method has been used to remove glare caused by water droplets. Fig. 9 shows a typical arrangement of the scene, the optical shutter array unit and the camera. Our system is not waterproof, so it is impossible perform the experiment in rain condition. We put water droplet to LCD panel using glass rod.

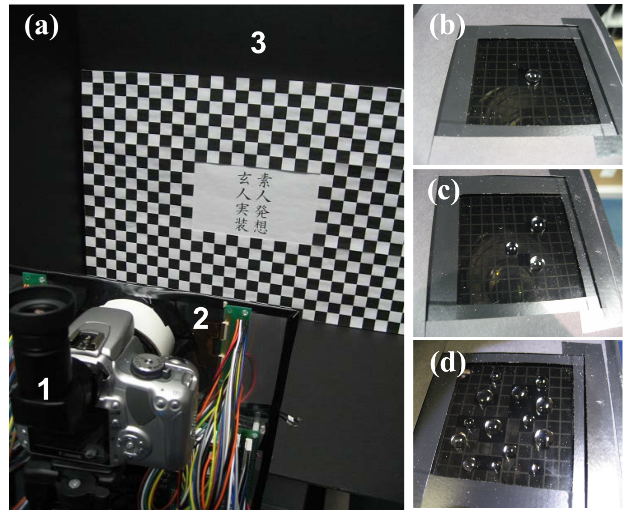


Figure 9: A typical arrangement of the scene. (a) We set up the optical the camera (1), shutter array unit (2) and the pattern (3) like this. (b)(c)(d) We then put water droplets on the optical shutter array.

Fig. 10 shows experimental results. For the first two results (a)(b), we set a pattern in front of the camera, and the others are outdoor experiment results. In the first result (a), we put one water droplet on the optical shutter array. Glare is caused by a ceiling light (fluorescent light). In the second result (b), we put on fourteen water droplets and use a high-luminance LED light to enhance glare. In the third result (c), we put one water droplet under clear weather conditions. In this case, glare is caused by sunlight. In the fourth result (d), we put one water droplet, and for the fifth result (e) we put three water droplets. These two images include bright light in the scene, so the veiling glare appears even if there is no water droplet.

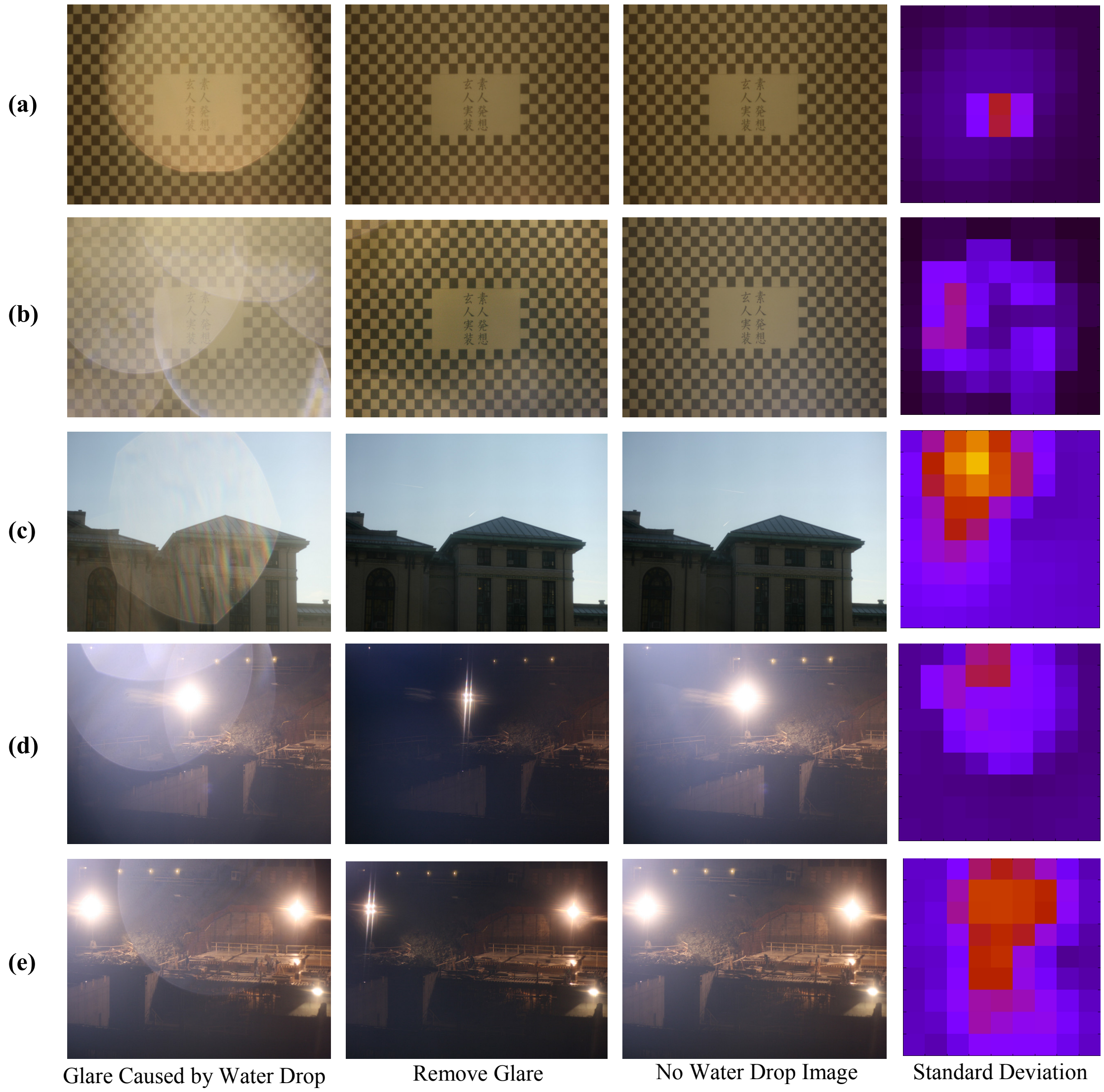


Figure 10: Experimental results of removing glare. The first column has images that have glare caused by water drops. The second column has images with the glare removed using our method. The third column shows images that have no water drops. The fourth column contains plots of standard deviations that are used to detect water drop positions.

Table 1 shows each camera setting and processing time. It takes 1 second to send each picture's data from the camera to the PC. That means to record all of the pictures required for glare removal, the time to record equals 100 seconds plus 100 times exposure time. After recording the photographic data, the processing time to detect the position of water droplets is about 4 to 5 seconds. (Panasonic Let's Note CF-Y7, 1.2GH z CentrinoDuo, 2GB RAM, WindowsXP)

	Total Processing time (sec)	Exposure time (sec)	F Value	ISO
a	108.3	1/25	1.8	400
b	108.5	1/25	1.8	400
c	105.1	1/800	2.5	100
d	108.3	1/25	1.8	400
e	108.2	1/25	1.8	400

Table 1: Camera setting and Processing time.

There are some limitations in our method. The biggest limitation is that our method requires a large number of photographs to detect a water droplet's position, so, for now, we can only apply it to static scenes. When water droplets move, transform, increase or decrease, our method does not work. If all optical shutter elements are covered by the water droplets, our method does not work. We must set the optical shutter directly in front of the imaging lens, or the optical shutter itself appears in the imaged of the scene. The image may become dark, depending on the number of closed shutters in the array. In addition, the loss of light is large because of the limited transparency of the LCD panel. The degree of liquid crystal cell transparency is about 40% or less. The LCD itself also introduces diffraction, spoiling the quality of the resulting image (See Fig 10 (d)(e), The star pattern is generated by diffraction around the light source). Despite these limitations, we believe our method is good for a variety of fields, especially surveillance or television broadcasting.

In the experiment, we found our method can reduce not only glare caused by water droplets but also general glare caused by scattering on the imaging lens and camera body (see Fig. 10, last two results). We have an extra experiment and Fig. 11 shows the result. In this experiment, we set a bright LED light in the scene. Using our method, general glare is reduced and halation is removed. We assume that the general glare is caused by a part of the lens surface, and our method detects that area and reduces general glare. Because of the low extinction ratio (about 105) of the LCD, we cannot block light perfectly. Thus, we cannot completely remove glare caused by very bright lighting (see Fig. 11(b)). When we find a more ideal optical shutter, this problem will be addressed.

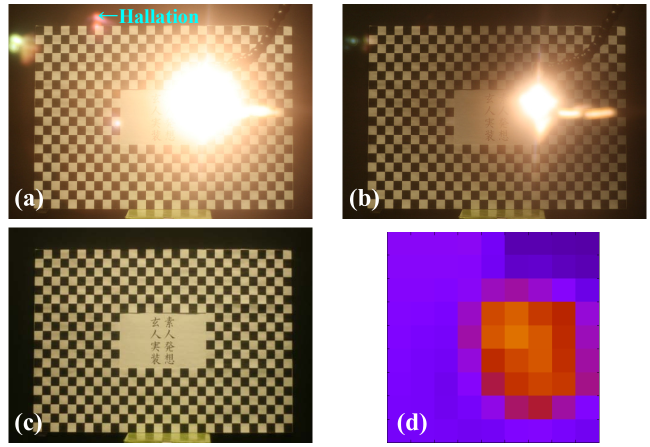


Figure 11: Additional general glare removing experiment. (a) We set a high-luminance, LED light in the scene. Veiling glare appears. (b) Experiment results in a general reduction of glare and halation is removed. (c) Ground Truth. (d) Plot of standard deviation.

7 Conclusion

We have developed a method to detect and remove the effects of water droplets that cause glare using optical shutter array. Our method is easy to implement with commercially available digital cameras.

Our method can only apply to static scenes, and the image become dark because we use LCD panel as an optical shutter. The ideal optical shutter for our method has not been developed yet. In the future, we will try to use DLP as optical shutter. DLP, known as the digital micro mirror device, is an optical semiconductor that loses less light than a LCD. However, the DLP requires more space and is more expensive than a LCD.

In this time, our method has some limitations as already stated. However, we address these limitation, removal of general glare in the moving scene in the future. We believe our method is useful for TV broadcasting or surveillance field.

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