Possibility of Deblurring Aerial Image Based on Deconvolution Processing

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ABSTRACT

This paper proposes deblurring an aerial image formed with aerial imaging by retro-reflection. We have measured the point spread function (PSF) according to the incident angle to the retro-reflector. Simulated results show possibility of deblurring the aerial image by applying the deconvolution processing based on the obtained PSF.

1 INTRODUCTION

Aerial display technique, which forms a real image in the mid-air, has been proposed as a future display. Aerial image by retro-reflection (AIRR) is suitable for displaying a large size aerial image [1] because AIRR features a wide viewing angle, scalability, and mass-productive optics.

Fig. 1 shows the principle of a floating image by a beam-splitter and a retro-reflector [2]. Light emitted from a light-source display is reflected once by a beam splitter. The reflected light returns to the original direction by a retro-reflector. A portion of the retro-reflected light transmits through the beam splitter. The transmitted light converges to the plane-symmetrical position of the light-source display regarding to the beam splitter.

Conventionally, some aerial imaging technologies have been proposed. Among them, AIRR has higher scalability in size of components than the others. Therefore, it is easy to customize the display position and size according to the situation. We have been applying AIRR for a large-size aerial signage system [3]. Displaying a large 56-inch aerial image, we have realized a new display system that allows viewers to pass directly through the aerial image.

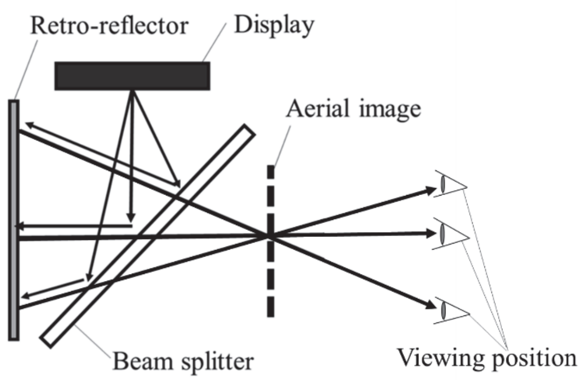

Fig. 1 Principle of AIRR.

We faced a problem in order to realize a large-size aerial display. The formed aerial image is blurred when the distance of the aerial image from the retro-reflector becomes long. This is because the retro-reflected light spreads due to the diffraction caused by the aperture of the corner-cube element in the retro-reflector.

It was reported that a deconvolution processing corrects the blur in the aerial image that is formed with a dihedral corner reflector array [4]. However, as shown in Fig. 2, the aperture width of the retro-reflective element changes in accordance with the incident angle of light. Because diffraction pattern depends on the aperture, the diffraction changes according to the viewpoint position. Thus, the point spread function (PSF) in AIRR depends on the viewpoint position.

The purpose of this paper is to optimize the aerial image quality that changes with the arrangement angle of the retro-reflector. First, we analyze the PSF of the aerial image using the angle of the retro-reflector as a parameter. Then, deconvolution processing has been performed on the aerial images observed at different directions.

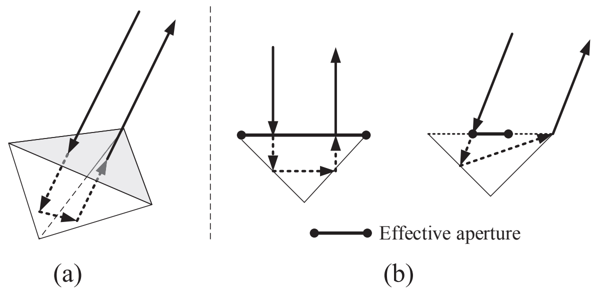

Fig. 2 Schematic diagram showing change of effective aperture size according to the incident angle to a corner cube. (a) A corner-cube in a retro-reflector. (b) When the incident angle increases, the effective aperture size reduces.

2 MEASUREMENT EXPERIMENT

This section describes experimental methods and results of PSF analysis of aerial images.

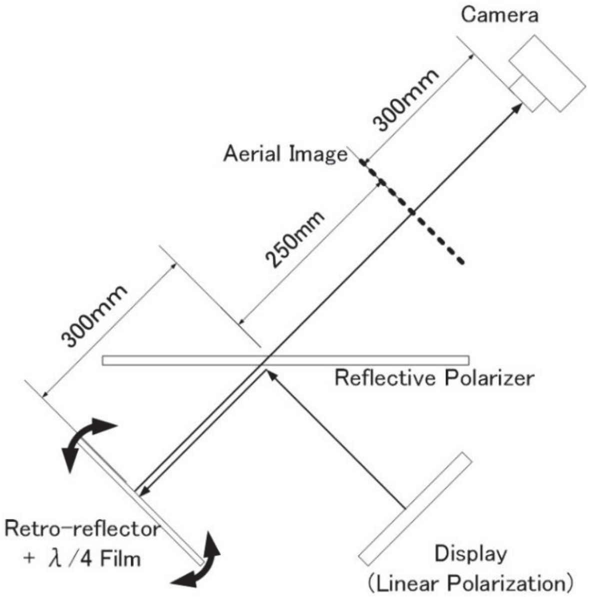

Fig. 3 Experimental setups for PSF measurements.

2.1 Measurement Environment

Fig. 3 shows a PSF measurement environment in which the placement angle of the retro-reflective material. The placement angle is varied in the experiment. We analyze blurring from an image captured by projecting a test image on aerial image. The light-source display is a high luminance LCD with a peak luminance of 960 cd/m^2. We use a reflective polarizer as the beam splitter, and add a λ/4 retardation film on the retro-reflector. Thereby, the linearly polarized light from the LCD converges to the aerial image position with a high efficiency [5]. The retro-reflector used in the experiments is composed of corner-cube elements. The retro-reflector is rotated about one axis orthogonal to the camera direction. We set the camera parameters manually (F20, 1/10sec, ISO800). The distances among the camera, the aerial image, and retro-reflector were fixed.

Fig. 4 shows the input image to the light-source display. We take the center of the aerial image and calculate the PSF from the captured image and the input image.

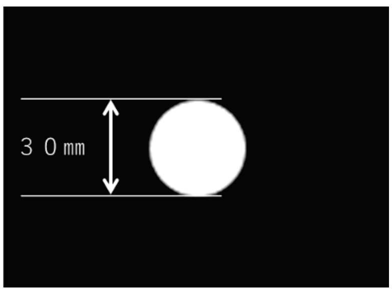

Fig. 4 Input image.

2.2 Measurement Results

Fig. 5 shows aerial images by rotating the retro-reflector. The 0-degrees angle means the angle orthogonal to the camera direction. The positive and the negative angles are the upward and the downward rotations, respectively. Fig. 6 shows the calculated PSF distributions from the images in Fig. 5. Shape of PSF depends on the angle. As the angle increases, the aerial image is blurred and dark, and the PSF spreads concentrically.

The analysis shows that the spread of PSF has a direction. Fig. 7 shows the result of the normalized PSF value for the vertical direction in Fig. 6. Fig. 8 shows the result of the normalized PSF value for the 45-degrees downward direction in Fig. 6. In Fig. 7, the PSF spreads regardless of whether the angle is positive or negative. In Fig.8, however, there is a difference in how the PSF spreads in the positive and negative directions.

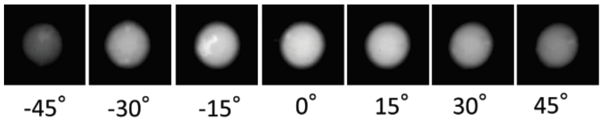

Fig. 5 Aerial images observed with varying the angle of the retro-reflector.

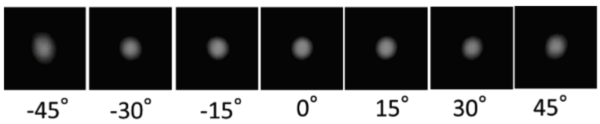

Fig. 6 Obtained PSF at the rotation angle of the retro-reflector.

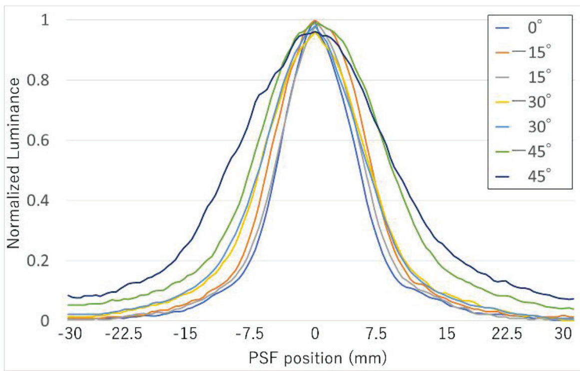

Fig. 7 PSF profiles along the vertical direction shown in Fig. 6.

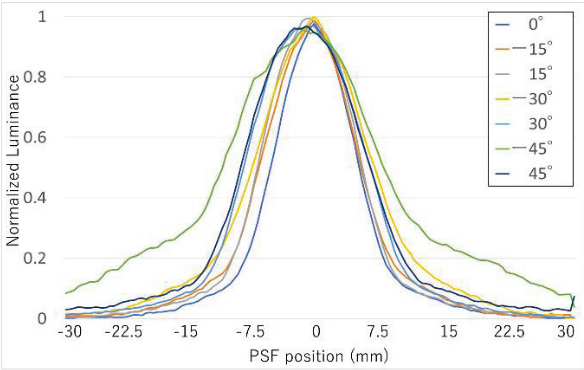

Fig. 8 PSF profiles along the 45-degrees downward direction shown in Fig. 6.

3 DEBLURRING AERIAL IMAGE

This section describes our deblurring method and results using the PSF analyzed in the previous section.

3.1 Deconvolution Processing

The PSF can be regarded as an impulse response in image signal processing, and blurred aerial image is represented by convolution of the input image and the PSF. Therefore, by designing the inverse filter for the PSF and performing the deconvolution process on the input image, it is possible to remove the blur of the aerial image. The inverse filter is designed using a Wiener filter including noise removal.

In this paper, we conduct two experiments to verify whether deblurring aerial image is effective. The first is the deconvolution of the camera image taken from the aerial image in the environment that was tasted in Fig. 3. We confirm whether the inverse filter created by PSF is effective in correcting the blur of the aerial image in the captured image. Fig. 9 shows the input image to the light-source display in the experiments. Secondly, in order to confirm whether the deblurring method of this paper is effective in human visual characteristics, we visually confirmed the results of aerial display of the deconvolved input image in an environment where the blur of the aerial image is noticeable. We constructed the environment in which the distance between the members in Fig. 3 was increased. We change the distance between the aerial image and beam splitter to 1200mm. The light-source display is a LED display with a peak luminance of 1200 cd/m^2 and a pixel pitch of 1.5 mm. We use a transparent glass plate as the beam splitter and the retro-reflector with a corner cube without a λ/4 retardation film. We measured two types of PSF with a retroreflective angle of 0-degrees and 45-degrees upward, and implemented deblurring. If the input image in Fig. 9 is applied for the deconvolution process, a gradation value of 0 or less is output. Therefore we apply an image with a compressed contrast ratio.

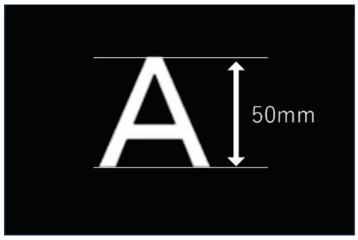

Fig. 9 Input Image.

3.2 Results of Deblurring Aerial Image

Fig. 10 shows the results of the first experiment that applying the deconvolution processing to the captured aerial images. The input is an image and the aerial image is blurred in outline according to the angle of the retro-reflector. The deconvolution processing uses the PSF shown in Fig. 6. Thus, different kernel was used depending on the angle. As shown in Fig. 7 (b), although the peak luminance is low depending on the angle of retro-reflector, its sharpness is improved.

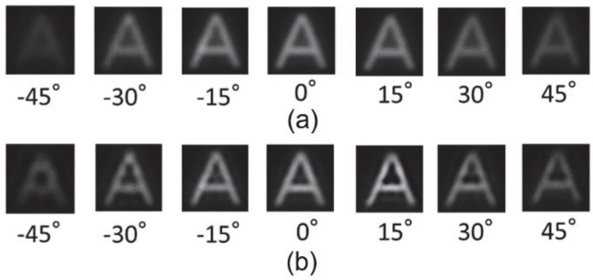

Fig. 10 Results of applying deconvolution processing to the captured aerial images. (a) Formed aerial images. (b) Deblurred images.

Fig. 11 shows the PSF in the environment of the second experiment. Compared with Fig. 6 through Fig. 8, the PSF in this environment is spread, and the aerial image is also greatly blurred. Fig. 12 shows the display results comparing the presence or absence of deblurring in the second experimental environment. Although the sharpness improvement by the deblurring process can be confirmed, it is visually less effective than the first experiment. It is because that the greater the blur, the lower the contrast ratio of the input image itself and the lower the visual improvement effect. In addition, as the experimental environment becomes larger, the error in the incident angle of the retro-reflector increases, and the PSF result becomes bad. Therefore, in order to appropriately perform the deblurring process, it is necessary to consider the finer PSF measurement and the optimization of the display image quality as preprocessing as the blur becomes larger.

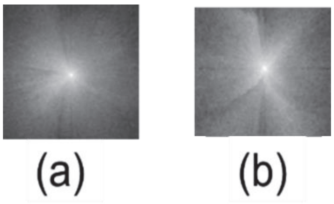

Fig. 11 PSF with the retro-reflector angle of (a) 0-degrees, and (b) 45-degrees upward.

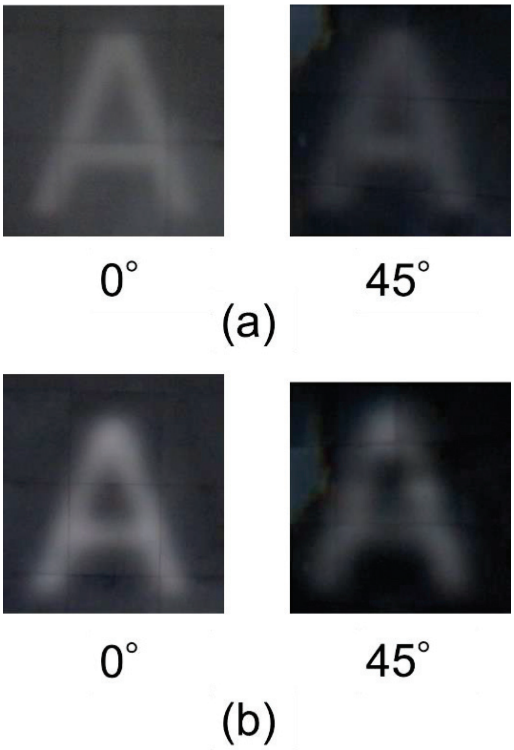

Fig. 12 Results of applying deconvolution processing to the input images with varying the angle of the retro-reflector. (a) Input images (b) Deblurred images.

4 CONCLUSION

We have analyzed how the light spreads according to the incident angle to the retro-reflector in AIRR, and confirmed the deburring correction effect by the convolution processing by the inverse filter.

Our proposed technique suggests the possibility to improve the display quality of the aerial image according to the viewers position. In particular, deblurring is an important issue in a large-sized aerial display system, where the distance from the retro-reflector to the aerial image becomes long and blurring of the aerial image becomes noticeable. The obtained results show not only the possibility but also effectiveness of deconvolution processing by use of using different kernel depending to the viewing direction. We believe that it is necessary to consider the positional relationship with the viewer and the usage environment when building a large aerial display system.

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