Examination of Deblur Processing for Full-color Aerial Image According to the Light Wavelength

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ABSTRACT

This paper proposes a deblurring an aerial image that changes with each optical wavelength. We have measured the point spread function (PSF) for each light wavelength. 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]. Figure 1 shows the principle of AIRR. 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. We have been applying AIRR for a large-size aerial signage system [2].

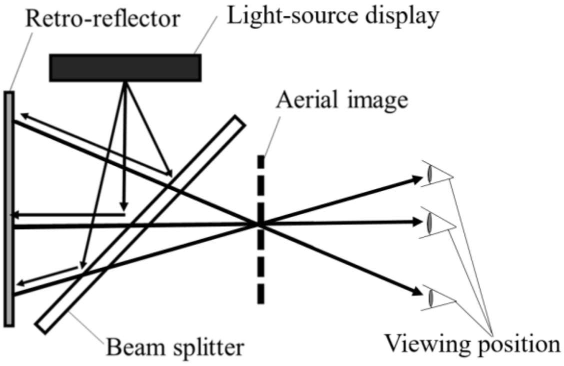


Fig. 1 The principle of AIRR

The optical system that forms the aerial image has a unique blur. This blur becomes more influential as the distance between the aerial image and the retro-reflector increases. That is because the retro-reflected light spreads due to the diffraction caused by the aperture of the corner-cube element in the retro-reflector.

The change in the resolution of the aerial image due to diffraction is measured by the change in the modulation transfer function according to the change in the diffraction pattern [3]. It was reported that a deconvolution processing corrects the blur in the aerial image that is formed with a dihedral corner reflector array [4]. Moreover, when applying aerial image technique to display system, it is necessary to adapt to changes in blur caused by various environments. In the related research, the change in the diffraction pattern of the retro-reflective element depending on the viewpoint position is measured, and the correction is made based on the result [5].

However, its research only measures the point spread function (PSF) for single-wavelength light sources and does not support light sources with multiple wavelengths. Since the diffraction of light is wavelength-dependent, it is necessary to make corrections according to the wavelength of the aerial image to be displayed. Further, the size of the diffraction aperture changes depending on the shape of the element of the retroreflective material, and the influence of blurring due to the change in the wavelength of light also changes. The purpose of this paper is to investigate the change of the PSF with the wavelength of the light source in AIRR and to show the possibility of optimally correcting blurring of aerial images by using PSF according to the color of the aerial image.

2 Experiment

In this experiment, we measured PSF for multiple retro-reflector using three types of wavelength light sources: red, green, and blue. Then, deconvolution processing has been performed on the aerial images observed at different directions. Figure 2 shows an experimental setup for PSF measurements. In this measurement, the analysis is performed from an image captured by projecting a test image on an aerial image. The light-source display is a high luminance LCD with a peak luminance of 960 cd/m2. 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 [6]. The retro-reflector is composed of corner-cube elements, and we have prepared the following three types of sheets with different specifications.

(1) Nikkalite RF-Ay,
(2) Nikkalite RF-Ax,
(3) Nikkalite RF-AC

We set the camera parameters manually (F20, 1/10sec, ISO800). The distances among the camera, the aerial image, and retro-reflector were fixed. Figure 3 shows the input image to the light-source display. For the wavelength of each input image, we prepared three types of test images showing the following wavelengths when measured with the Light Measurement Device.

(1) Red : 639nm,
(2) Green : 530nm,
(3) Blue : 465nm

We take the center of the aerial image and calculate the PSF from the captured image and the input image.

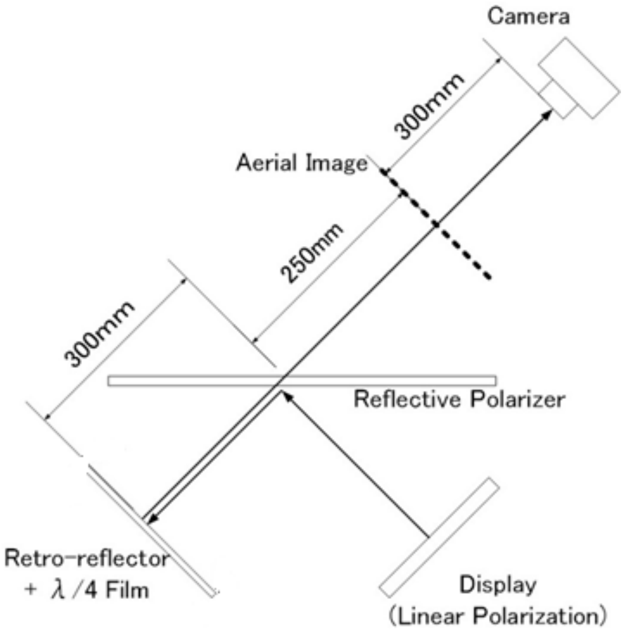


Fig. 2 Experimental setup for PSF measurements.

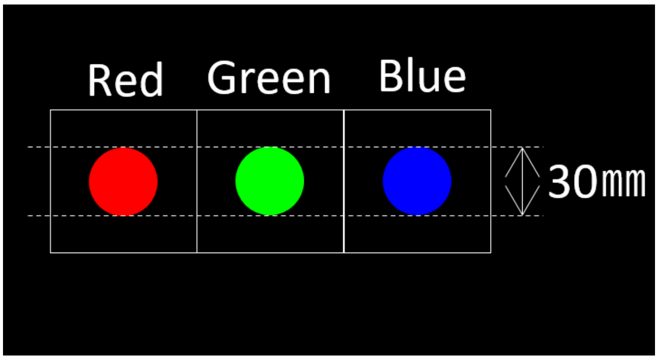


Fig. 3 Input image

3 Results and Discussion

Figure 4 shows an aerial image set captured for each retro-reflector and each wavelength. Figure 5 shows the results of calculating PSF from the image set of Figure 4. PSF normalizes the center position with the maximum value of 1, and indicates that the larger the value in the two-dimensional region, the more blurry the direction seen from the center. From the results of this experiment, it was confirmed that the PSF spreads differently depending on the wavelength. In the order of Red, Green, Blue, the spread of PSF becomes large and the blur becomes large. Furthermore, it was confirmed that different characteristics appear in the size and direction of the spread of the PSF according to the difference in the specifications of the retro-reflector. This suggests that the difference in the retroreflective element structure causes a change in the two-dimensional shape of the aperture, and the PSF changes not only in size but also in directionality.

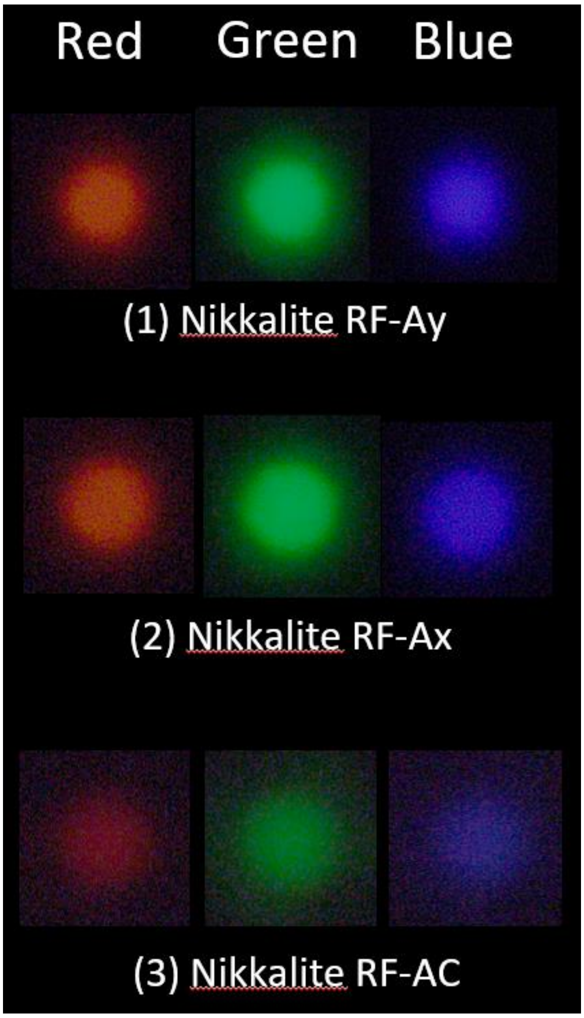
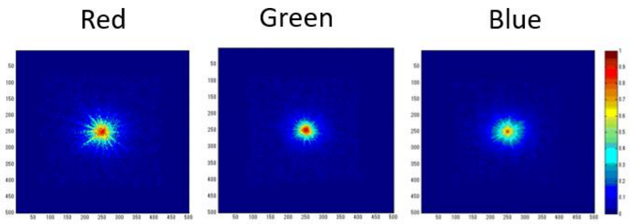
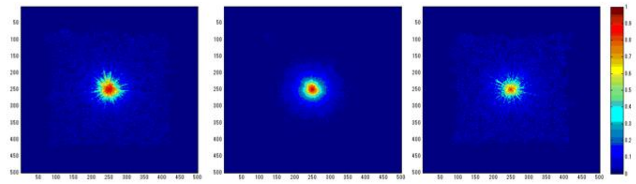


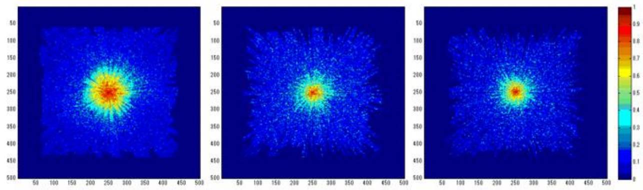
Fig. 4 Aerial images observed with varying the wavelength.



(1) Nikkalite RF-Ay



(2) Nikkalite RF-Ax



(3) Nikkalite RF-AC

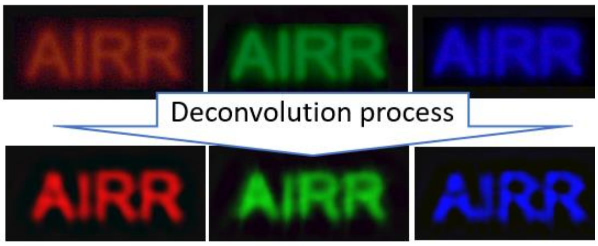
Fig. 5 Results of PSF.

Figure 6 shows the result of applying the deconvolution process to the captured aerial image. The input image displays the characters "AIRR". In this process, the PSF shown in Figure 5 is used as a filter function, an inverse function is calculated, and a deconvolution process is applied to the input image to generate a corrected image.

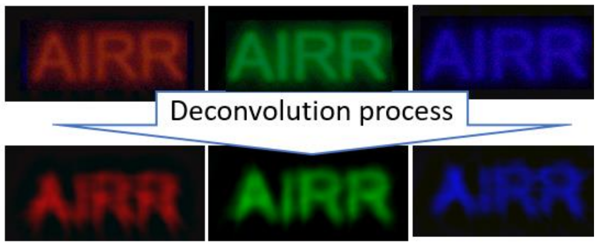
Focusing on the difference in the specification of the retro-reflector in the Figure 6, it can be confirmed that an image in which the contrast of the edge portion is emphasized is generated against each blur. However, with the specification of Nikkalite RF-AC, it is presumed that an appropriate corrected image cannot be constructed because the blurring is too large and the contrast ratio of the aerial image is lowered.

It was confirmed that the readability of the characters in the aerial image of the output image changed for each wavelength, and the effect of blur correction was also different. In Red, which has a longer wavelength, blurring spreads around the characters over a wider area, and the contrast ratio at the edges of the characters decreases. Further, the longer the wavelength, the larger the pixel range affected by the correction process by the deconvolution process, so that the shape is more likely to collapse than the original image..

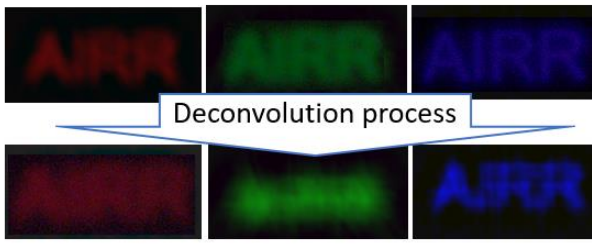
(0) Input Image



(1) Nikkalite RF-Ay



(2) Nikkalite RF-Ax



(3) Nikkalite RF-AC

Fig. 6 Results of applying deconvolution processing to the aerial images.

4 Conclusions

In this paper, the blurring characteristics, which depend on the specifications of the retro-reflector and the wavelength of the light source, were measured by PSF. As a result of the measurement, it was confirmed that the PSF spread changed depending on the element shape of the retroreflective material, and that the PSF spread became larger as the wavelength of the color was larger than that of the element shape. In addition, from the obtained PSF results, blur correction of aerial images optimized for each of the three characteristic primary colors by deconvolution was performed, and the effect was confirmed. When the blurring was small with respect to the size of the characters, it was visually confirmed that the contrast ratio in the edge region of the aerial image was improved by the correction processing, and the readability and visibility of the characters were improved. On the other hand, in the case of a blurring characteristic in which the PSF spreads widely, the contrast at the edge of the aerial image becomes low, and there is a result that appropriate correction processing is not performed. From this, it is considered that an optical structure design for applying the correction process is required.

This can be expected as a improvement approach of correcting the blur of AIRR by image processing technology instead of optical structure technology. In recent years, in the display application of aerial image display technology, not only spatial lighting with a single light source but also full-color aerial image display using an LCD or LED display as a light source is expected. We will continue to study blur correction methods for aerial images by image processing according to other optical elements, and aim to realize a higher-definition aerial display system that can be applied to various optical structures.

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