Reduction of Blur of Aerial Image Formed with AIRR by Use of Paired Masked Retro-reflectors

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ABSTRACT

We propose a new optical system to form an aerial image by use of a pair of masked retro-reflectors. The masked edge increases sharpness of the aerial image. Because the retro-reflectors are masked complementarily so as to have a negative-positive relationship, there is no missing part of the aerial image.

1 INTRODUCTION

AIRR (aerial imaging by retro-reflection) can form aerial LED signage [1]. Aerial LED signs are expected for such applications as placing traffic signs in tunnels that do not obstruct air flow in positions and also that are easy for drivers to see. In such applications, long floating distances exceeding 1 meter are required. However, the size of the point spread of the aerial image with AIRR increases in proportion to the distance from the retro-reflective element to the aerial image [2].

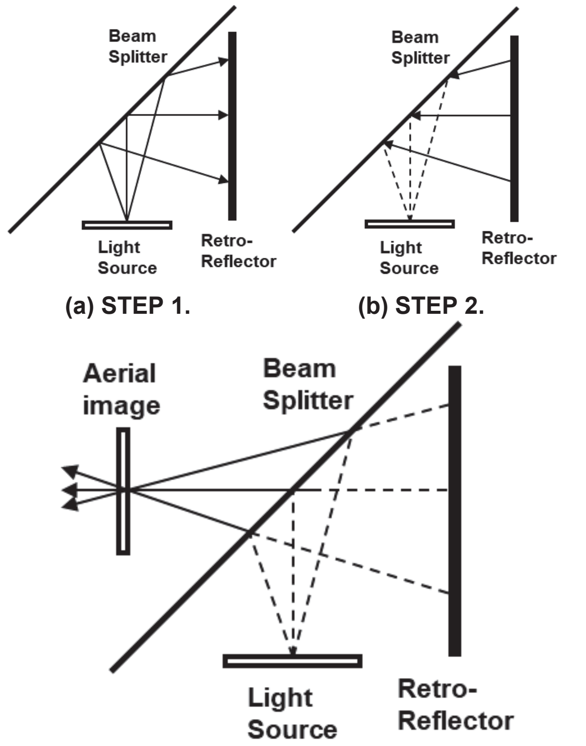
Therefore, in our previous research, the retro-reflection sheet was processed to reduce the apparent blur based on the idea that the light incident on the observer's pupil determines the apparent blur [3]. The problem of this experiment is that it is assumed that an aerial image is seen from a long distance, so it is impossible to recognize what is reflected as an image when the aerial image is observed from a short distance. In order to fill the missing region of the formed aerial image, this paper proposes overlaying patterned aerial images. In this case we can reduce the apparent blur and overcome the difficulty of observing the aerial image by overlaying another aerial image with a reduced apparent blur so as to complement the patterned aerial image.

The purpose of this research is to propose an optical design that achieves both "reducing the apparent blur of the aerial image" and "recognizing the content displayed as an image even when observed at a short distance". The proposed optical system is demonstrated by use of a pair of retro-reflectors. Retro-reflective sheets are masked so that retro-reflective regions are complementarily located.

2 PRINCIPLE

2.1 AIRR

The principle of AIRR is shown in Fig. 1. Light rays emitted from a light source are reflected by a beam splitter (STEP 1). Next, the reflected light rays impinge a retro-reflector and return to the incident direction after retro-reflection (STEP 2). The retro-reflected light rays pass through the beam splitter and form the aerial image at the plane-symmetrical position of the light source with respect to the beam splitter (STEP 3). Fig. 2 shows an example of an aerial image that is formed with AIRR.



(c) STEP 3.

Fig. 1 Principle of AIRR (a) in STEP 1, (b) in STEP 2, and (c) in STEP 3.

Fig. 2 Aerial image formed with AIRR.

2.2 Difference of aerial image by retro-reflective materials

Previous studies have shown that the extent of blurring of point images when formed as an aerial image differs depending on whether the retroreflective material is composed of bead type or prism type, or what type of prism type product [4]. Fig. 3 shows the far-field patterns of the reflected light by use of a He-Ne laser beam as the light source. For a comparison, a mirror is used in Fig. 3 (a). Prism type retro-reflectors are used in Figs. 3(b) to 3(e). A bead type retro-reflector is used in Fig. 3 (f). The aerial image formed with a bead-type retro-reflective material has low retro-reflectivity, so the blur spreads out from the center of the aerial image. On the other hand, the blur of the aerial image formed with a retro-reflective material of prism type is reduced compared to the bead type. In comparison with the mirror, the far-field patterns of the retro-reflectors spread widely due to the diffraction. From this experiment, it was shown that the degree of blurring of the aerial image changes with retro-reflective material.

2.3 Apparent blur reduction by masked retro-reflective sheet

In the previous study, the retro-reflective sheet was processed to reduce the apparent blur based on the idea that “the light incident on the observer's pupil determines the apparent blur” [3]. When an aerial image is formed by retro-reflection, the blur is reflected in the aerial image by retro-reflecting up to the blurry part of the aerial image. Therefore, we thought that the “apparent blur” of the aerial image could be reduced by applying a process to widen the interval between retro-reflective materials. The retro-reflective sheet used in the experiment consists of 3-mm wide retro-reflective material arranged at 3-mm intervals. Fig. 4 (a) shows an aerial image formed by use of an unprocessed retro-reflective sheet. It can be seen that the image is blurred vertically and horizontally. Fig. 4 (b) shows an aerial image formed using a vertically-striped retro-reflective sheet. Compared to Fig. 4 (a), it can be seen that the apparent blur is reduced in the lateral direction where there is no space for retro-reflective material.

3 EXPERIMENTAL METHOD

3.1 Experimental setup

Fig. 5 shows the experimental setup used in this experiment. The light emitted from the light source is divided into light that travels to Retro-reflector 1 and Retro-reflector 2 by a half mirror.

When the light emitted from the light source is reflected by the half mirror, the reflected light impinges Retro-reflector 1. Then, the retro-reflected light passes through the half mirror. When the light emitted from the light source transmits through the half mirror, the transmitted light impinges Retro-reflector 2. Then, the retro-reflected light is reflected by the half mirror.

Thus, with the half mirror as the axis, these two lights combine to form an aerial image at a position symmetrical to the light source.

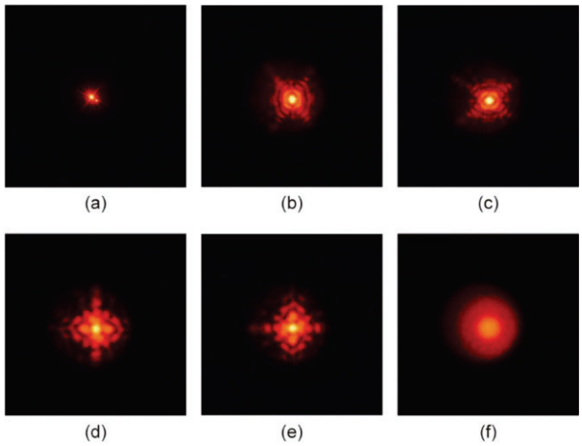


Fig. 3 Far-field patterns of reflected lights. (a) Mirror. (b) Longitudinal Nikkalite CRG. (c) Lateral Nikkalite CRG. (d) Longitudinal ReflexiteHA42. (e) Lateral Reflexite HA42. (f) 3M scotchlite 8910.

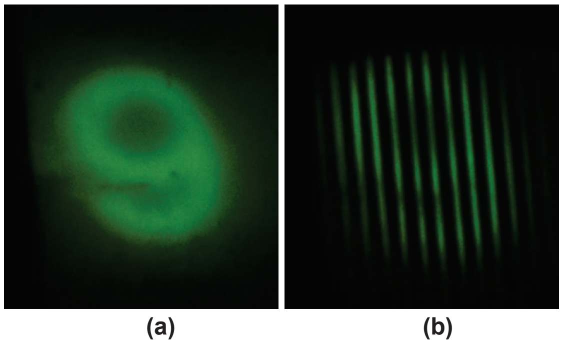


Fig. 4 Aerial images formed by use of (a) the normal retro-reflective sheet, (b) the retro-reflective sheet in vertical stripes.

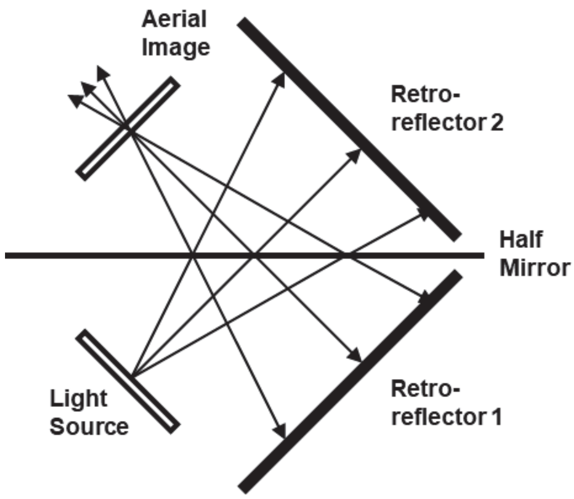


Fig. 5 Experiment setup.

3.2 Mask of retro-reflective sheet

Fig. 6(a) shows the retroreflective sheeting mask used in this experiment. The left half is not masked. The right half is masked in 3-mm increments. This mask is placed on two retroreflective sheets, and each is set to alternate, and its image is shown in Fig. 6(b). The first of the two merits of our proposal is "reducing the apparent blur of the aerial image" by applying a mask. Another merit is the overcome of “difficulty in observing aerial images caused by parts that are not formed as aerial images when observing aerial images masked at close range” by arranging two masks complementarily.

4 RESULTS

4.1 Experimental results

Fig. 7 shows the images used in the experiment. It is a test pattern. Its left and right sides show horizontal and vertical stripes, respectively. Between them, a square is located. The width of each striped pattern is equally spaced in both black and white. Positive and negative test patterns are prepared, as shown in Fig. 7 (a) and (b). In the lower half, the test pattern is drawn in white on a black background.

Fig. 8 shows the experimental results. In order to avoid the reflection of light by the retroreflective sheet itself, the shooting angle of the camera is different in the vertical direction.

In Fig. 8 (a), white blurring affects the central black square on the left half of the unmasked side, and the vertical and horizontal stripes on the left and the right are also greatly affected by white. On the right half mask side, the overall brightness is reduced because of the mask. However, it can be seen that both the outline and color of the test pattern are clearer than the left half.

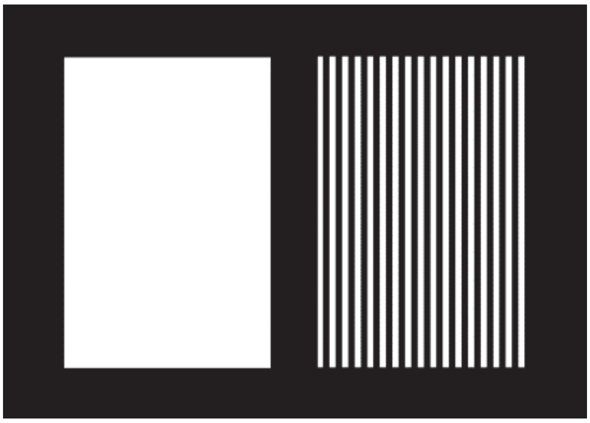
In Fig. 8 (b), it can be seen that the left half has high luminance, but the black part is blurred in white, and the black line is crushed at the horizontal stripes where black and white should be equally spaced. The right half, like Fig. 8 (a), is low in brightness as a whole, but has little white influence on the black part, and the center square has a clear outline. It can be seen that the phenomenon in which the black in the left half of the horizontal stripe is white is improved, and the width of black and white is also improved.

The observation difficulty problem has been overcome because there is no gap in the aerial image in the right half of each figure.

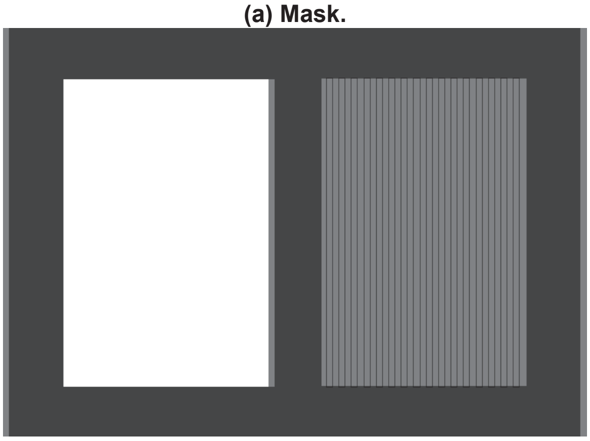
4.2 Comparisons of profiles

Fig. 9 and Fig. 10 show the intensity profiles of the horizontal stripes in Fig. 8 (a) and the vertical stripes in Fig. 8 (b), respectively. The profiles were obtained with ImageJ's PlotProfile and gave gray values.

Fig. 9 (a) shows the profile of the left horizontal stripe in Fig. 8 (a), and Fig. 9 (b) shows the profile of the right



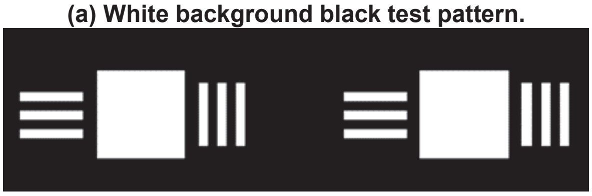
(a) Mask.



(b) Image of mask overlay.

Fig. 6 Mask and overlay used in this experiment.

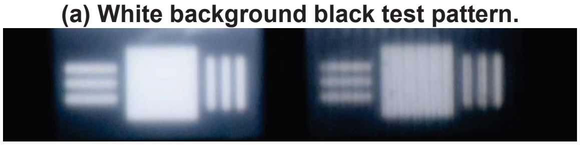
(a) White background black test pattern.



(b) Black background white test pattern.

Fig. 7 Test pattern.

(a) White background black test pattern.



(b) Black background white test pattern.

Fig. 8 Experimental results.

horizontal stripe in Fig. 8 (a). Comparing these two profiles, it can be seen that the maximum value of the gray value is larger in the case without the mask and the decrease value in the black part is lower. This suggests that a clear aerial image can be seen by applying a mask because a low gray value is desirable in the black area.

Fig. 10 (a) shows the profile of the left vertical stripe in Fig. 8 (b), and Fig. 10 (b) shows the profile of the right vertical stripe in Fig. 8 (b). Comparing the two, as in Fig. 9, the maximum gray value is higher without the mask and the decrease is greater with the mask.

5 CONCLUSIONS

By combining the retroreflective sheet with the mask, it was confirmed that both the reduction of the apparent blur of the aerial image and the improvement of the observation difficulty were satisfied. The future challenges includes how to prevent the brightness of the aerial image from decreasing with this experimental method.

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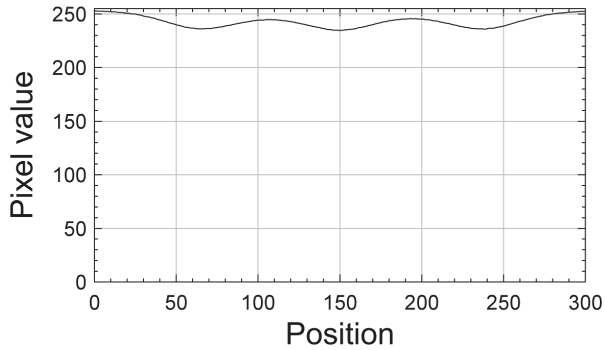
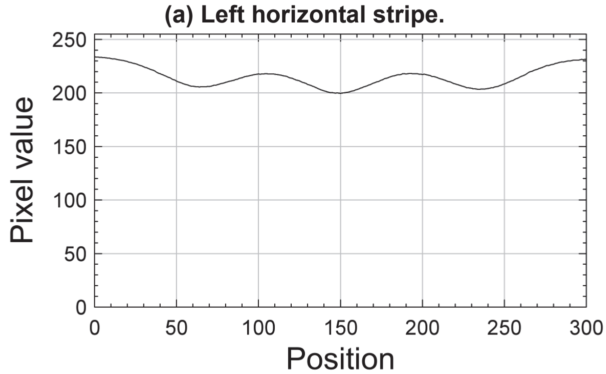
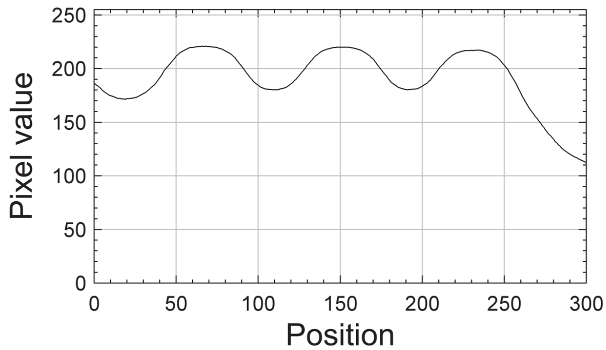


(a) Left horizontal stripe.

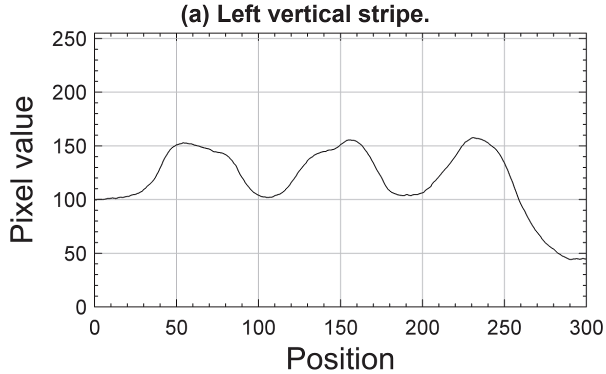


(b) Right horizontal stripe.

Fig. 9 Profile result of Fig. 8(a).



(a) Left vertical stripe.



(b) Right vertical stripe.

Fig. 10 Profile result of Fig. 8(b).