Change in Long-Range Pop-up Distance of Arc 3D Display Due to Substrate Installation Angle

Hiroto Oishi, Masaki Yasugi, Shiro Suyama and Hirotsugu Yamamoto

hirotsugu@yamamotolab.science

Utsunomiya University, Yoto 7-1-2, Utsunomiya, Tochigi 321-0904, Japan,

Keywords: arc 3D display, arc, scratch

ABSTRACT

We clarified the long-range pop-up distance to almost half of observation distance in front of the substrate of arc 3D display. Simulation of the pop-up distance by changing the angle of substrate installation leads that the pop-up distance increases as the substrate is shifted closer to the perpendicular of ground.

1 Introduction

There is a need to eliminate installations from the airspace above the main line on expressways. In July 1963, the Meishin Expressway between the Ritto and Amagasaki Interchanges opened as the first expressway in Japan. While the demand for expressways is increasing, the aging of expressway structures is accelerating. This aging led to a serious accident as the Sasago Tunnel of the Chuo Expressway in Yamanashi Prefecture in December 2012, in which a concrete ceiling fell over a 130 m section, killing nine people. Since this accident, large-scale renewal and repair of highway structures have been carried out. However, it is impossible to eliminate the risk of falling signs and information boards above the road as long as there are guide signs and information boards above the road.

We have proposed to realize road signs and information boards using pop-up image display technology. One technology suitable for application to road signs is arc 3D display [1, 2]. Arc 3D display is a technology that generates pop-up images by irradiating a substrate with arc-shaped scratches with highly directional light. Arc 3D display has a large viewing area not only in the horizontal direction but also in observation direction and allow observation of the pop-up images from a distance of several meters or more, and can generate pop-up images using car headlights as a light source, making them a good candidate for pop-up image display technology on expressways.

The future goal of our study is to realize the arc 3D display as a guide and information board. As a first step, we aim to apply the arc 3D display to directional signs used when lane restrictions are enforced on expressways. The number of directional signs required for lane restrictions is 50 at intervals of 20 m over a 1 km stretch, and the number of signs can be cut in half if a 20 m popping-up display can be realized. In a previous study, it was clarified that the pop-up distance of an aerial image changes as the observation angle changes. It has been shown that aerial images pop-up about 2 m in front of arc 3D substrate [3]. However, for application as a directional sign on expressways, it is necessary to realize a pop-up distance of 20 m.

In this study, focused on the installation angle of the arc 3D substrate, we clarified the change in the pop-up distance of the aerial image caused by the angle of the arc 3D substrate installation. Simulation of the pop-up distance with appropriate illumination and observation positions by changing the angle of substrate installation was clarified how much of the pop-up distance can be realized.

2 Principle of Arc 3D Display

The following explains the basic principle of the arc 3D display composed of arc-shaped scratches. When highly directional light is directed onto a transparent plate such as an acrylic plate, light is directionally irradiated, making specific locations on the arc-shaped scratches brightly illuminated.

When the light source, the eye, and the center “O” of the arc-shaped scratches are on a straight line, as shown in Fig. 1, all the arc-shaped scratches appear bright.

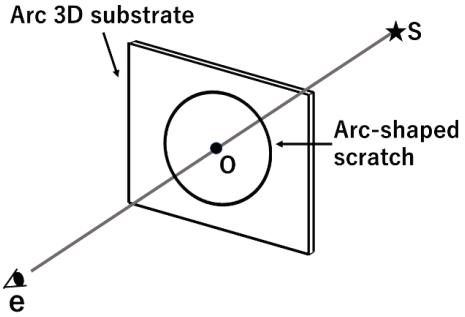

Fig. 1 When the line connecting the light source to one eye passes through the center of the arc-shaped scratch.

When the line connecting the light source to one eye does not pass through the center of the arc-shaped scratch as shown in Fig 2, P1 and P2, which are the points inscribed or circumscribed by the arc-shaped scratch, appear bright within the circle centered at “O”.

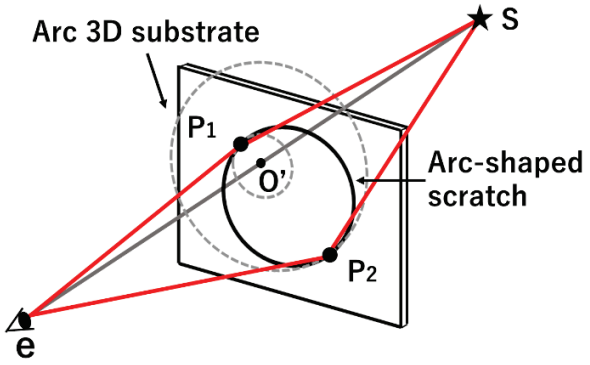

Fig. 2 When the line connecting the light source to one eye does not pass through the center of the arc-shaped scratch.

Fig. 3 shows when the arc-shaped scratch is observed with both eyes. The bright spots perceived by the right eye are P_{1R} and P_{2R}, and those perceived by the left eye are P_{1L} and P_{2L}. Since the bright spots perceived by the left and right eyes are different, G_1 and G_2 are perceived as popping-up images at the back and front of the substrate, due to binocular disparity.

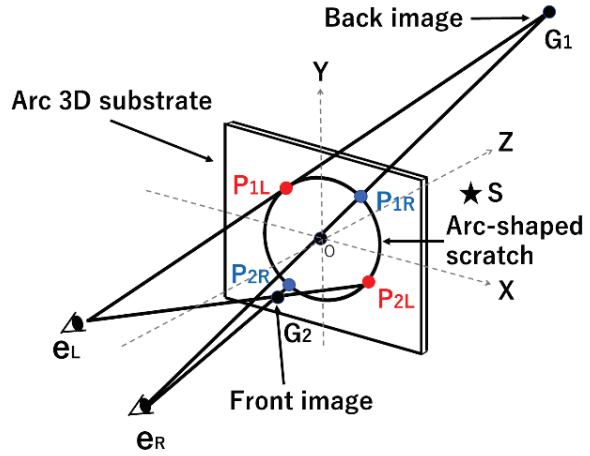

Fig. 3 When the arc-shaped scratch is observed with both eyes.

When the observation distance is sufficiently large, as shown in Fig. 4, the position of one bright spot for one eye changes as the eye moves horizontally and in the direction of the observation distance. This allows for a large observation area in the horizontal and observation distance directions.

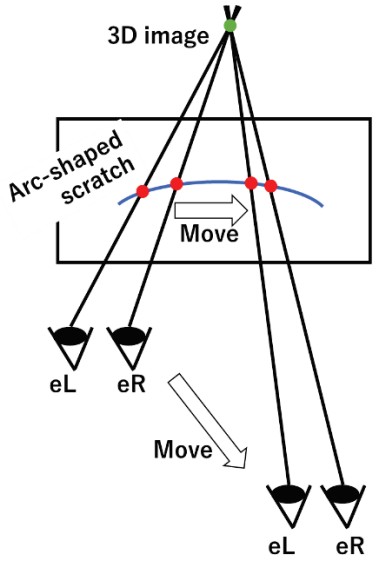

Fig. 4 Principle of smooth motion parallax at horizontal and depth directions.

3 Theoretical expression for pop-up distance

The theoretical expression for the pop-up distance of aerial image perceived in the arc 3D display has been clarified in previous study [2]. The theoretical expression for the pop-up distance Z_G is given by

$$Z_G = \frac{(X_{pr}-X_{pl})Ze}{(X_{el}-X_{er})+(X_{pr}-X_{pl})}. \quad (1)$$

Where X_{el} is the horizontal position of the observer’s left eye, X_{er} is the horizontal position of the observer’s right eye, X_{pr} is the position of the X-axis bright spot as perceived by the right eye, X_{pl} is the position of the X-axis bright spot as perceived by the left eye, and Z_e is the distance from the arc 3D substrate of the observer’s eye.

After deforming expression (1) to include the installation angle of the arc 3D substrate, the pop-up distance of the aerial image Z_G is expressed by

$$Z_G = -r\left\{\frac{1}{tan\theta-\tan(90-\alpha-\beta)}\right\}. \quad (2)$$

In this study, it is designed to install a mirror behind the arc 3D substrate, so the light irradiated from the light source is reflected by the mirror. In expression (2), r is the radius of the arc, the light reflected by the mirror is defined as the actual irradiation angle θ, where α is the angle of inclination of the arc 3D substrate to the ground and β is the angle of observation.

4 Simulation of pop-up distance by changing the installation angle of the substrate.

Using the theoretical expression for the pop-up distance given in section 3, we simulated the pop-up distance by changing the installation angle of the substrate . Based on the application as a directional sign on the expressway, the height of the observer and the light source were set as shown in the Fig. 5, and the aerial image was envisioned an arrow, as shown in Fig. 6.

The observer was set at 1.2 m, which is the eye height of a car driver on the expressway, and the light source was set as 0.6 m, which is the height of a car headlight, using an LED pseudo parallel light source (Pi-photonics: HOLOLIGHT). The arc 3D substrate was set to an arc radius of 1 m, 0.6 mto the same height as the light source. The distance between the light source and the arc substrate was set at 4 m.

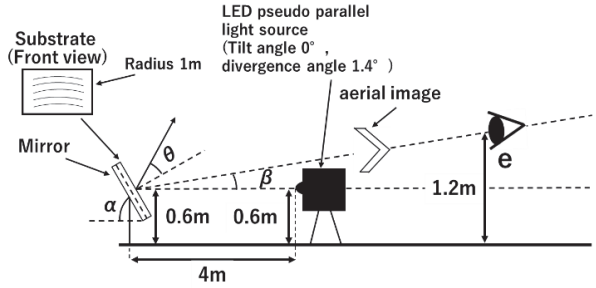

Fig. 5 Each parameter in the simulation.

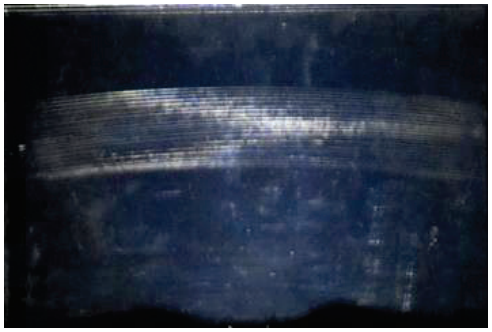

Fig. 6 Aerial image.

The simulation results of the pop-up distance by changing the installation angle of the substrate are shown in Fig. 7. The solid line in Fig. 7 represents an aerial image that can be perceived by an observer, and the dotted line represents an aerial image that can't be perceived by an observer. An unperceivable aerial image is an aerial image that satisfies one of the following conditions: either the reflected light from the mirror enters the eyes of the observer or the bright spots on the X-axis no longer fall within the substrate.

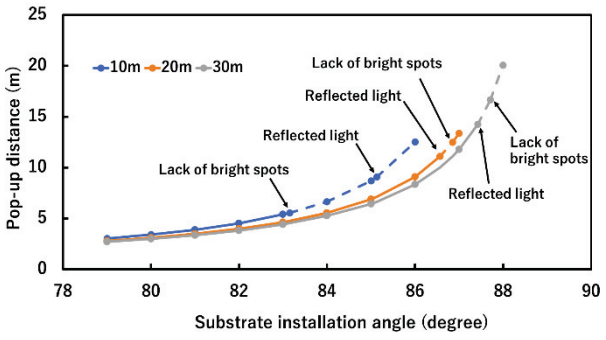

Fig. 7 Simulation of the pop-up distance by changing the installation angle of the substrate.

Fig. 7 shows that the pop-up distance of the aerial image changes as the substrate installation angle is changed. For all observation distances, the distance at which the aerial image popped-up increased as the installation angle of the arc 3D substrate was shifted closer to vertical to the ground. At each observation distance, a pop-up distance of 5.4 m can be realized with substrate installation angle of 83 degrees at the observation distance of 10 m. At the observation distance of 20 m, a pop-up distance of 9.1 m can be realized with substrate installation angle of 86 degrees and the observation distance of 30 m, a pop-up distance of 12 m can be realized with substrate installation angle of 87 degrees.

A graph of the amount of the change in the pop-up distance as a change in the installation angle is shown in the Fig. 8.

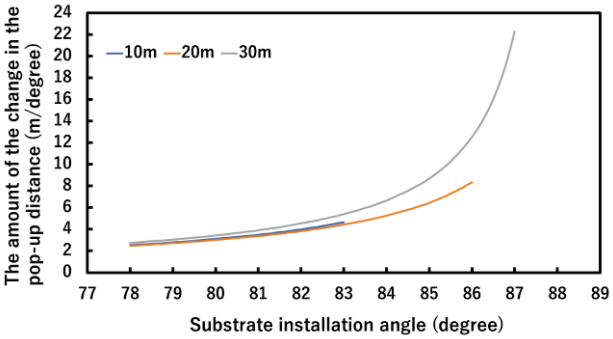

Fig. 8 The amount of the change in the pop-up distance as a change in the installation substrate angle.

Fig. 8 shows the amount of the change in the pop-up distance as a change in the installation substrate angle. At observation distances of 10 m and 20 m, the amount of pop-up distance caused by the change in the angle of substrate installation was small, indicating that the error in the pop-up distance of aerial popping-up image caused by the change in the angle of substrate installation was small. At the observation distance of 30 m, the amount of change in the pop-up distance becomes larger as the installation substrate angle increases, and the more one tries to perceive an aerial image with a large pop-up distance, the more error occurs in the pop-up distance of the aerial image, but because the observation distance is 30 m which is very far away, the error is not considered to be of much concern.

5 Conclusion

In this study, we clarified the change in the pop-up distance of the aerial image caused by a change in the angle of the arc 3D substrate installation. The theoretical

expression for the pop-up image was deformed to include the installation angle of the substrate, and the pop-up distance of an aerial image was simulated at each observation distance by changing the installation angle of the substrate. The simulation results showed that the pop-up distance of the aerial image changed as the installation angle of the substrate was changed. Furthermore, the closer the installation angle of the substrate is vertical to the ground, the larger the pop-up distance of the aerial image became, indicating that a pop-up distance of 12 m can be achieved at an observation distance of 30 m.

Next, we would like to simulate the pop-up distance in terms of arc radius and substrate size in order to achieve a 20 m pop-up distance.

Acknowledgements

A part of this work was supported by JSPS KAKENHI (19H04155, 20H05702).

References

[1] Y. Sato, I. Saji, S. Suyama, and H. Yamamoto, “The blur width of the bright spot can be reduced by increasing the observation distance in the front projection of the arc 3D display,” Proc. DHIP 2021, P. 22 (2021).

[2] Y. Sato, I. Saji, M. Yasugi, S. Suyama, and H. Yamamoto, “Fabrication and Observation of Arc 3D Display with a Long Floating Distance,” ITE Technical Report, Vol. 46, No. 9, pp. 89-92 (2022). [in Japanese]

[3] S. Suyama, H. Mizushina, and H. Yamamoto, “Theoretical and Experimental Perceived Depths in Arc 3D Displays: On/Off Switching Using Liquid-Crystal Active Devices,” in IEEE Industry Applications Magazine, Vol. 27, No. 1, pp. 69–81 (2020).