Air Floating Image based on a Dihedral Corner Reflector Array

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ABSTRACT

An air floating image and its applications based on a dihedral corner reflector array are introduced in this paper. An observer can see the air floating image by the naked eye and manipulate it by touching the air floating image using finger sensor system.

1 INTRODUCTION

An air floating image display attracts attention in the field of hyper-realistic display system. This type of display does not require a head-mounted device or special glasses, so it has the advantage that even a passing observer can see an air floating image. Various types of aerial imaging displays have been developed including air floating like image displays, such as pepper's ghost, and real air floating image displays, such as using an optical imaging element including autostereoscopic displays [1-6], a fog screen [7] or plasma emission [8]. In the latter systems, observers' finger pass through the air floating image when they try to touch it. This experience can strongly attract their interest, so this type of display can be suitable for advertising and entertainment. Moreover, they can be applied to non-contact touch display that has high cleanliness.

In recent years, development of optical imaging element type is progressing. One of the most promising methods is based on retro-reflection or transmissive retro-reflection [1-4]. Parity Innovations Co. Ltd. has been developed a dihedral corner reflector array (DCRA) [1, 2] that is a transmissive retro-reflective imaging element.

In this paper, basic principle of an air floating image display using the DCRA is introduced. In Section 2, configuration and imaging basis are described. In Section 3, result of an air floating image display using the DCRA is shown. In Section 4, conclusion and future works are described.

2 DIHEDRAL CORNER REFLECTOR ARRAY

DCRA can be made from transparent resin by thermal nanoimprint with a fine metallic mold. Figure 1 shows a schematic diagram of the DCRA and the ray paths. The DCRA consists of many pillars whose sidewall works as a roof mirror, that is, the adjacent two sidewalls are orthogonal and vertical planar reflecting surfaces. Note that there are draft angles on the opposite side of the adjacent two walls for mold release in process of nanoimprint; these draft angle surfaces cannot form an air floating image. Typically, the size of the pillar is approximately 200μm square, and the depth of the pillar is approximately 300μm.

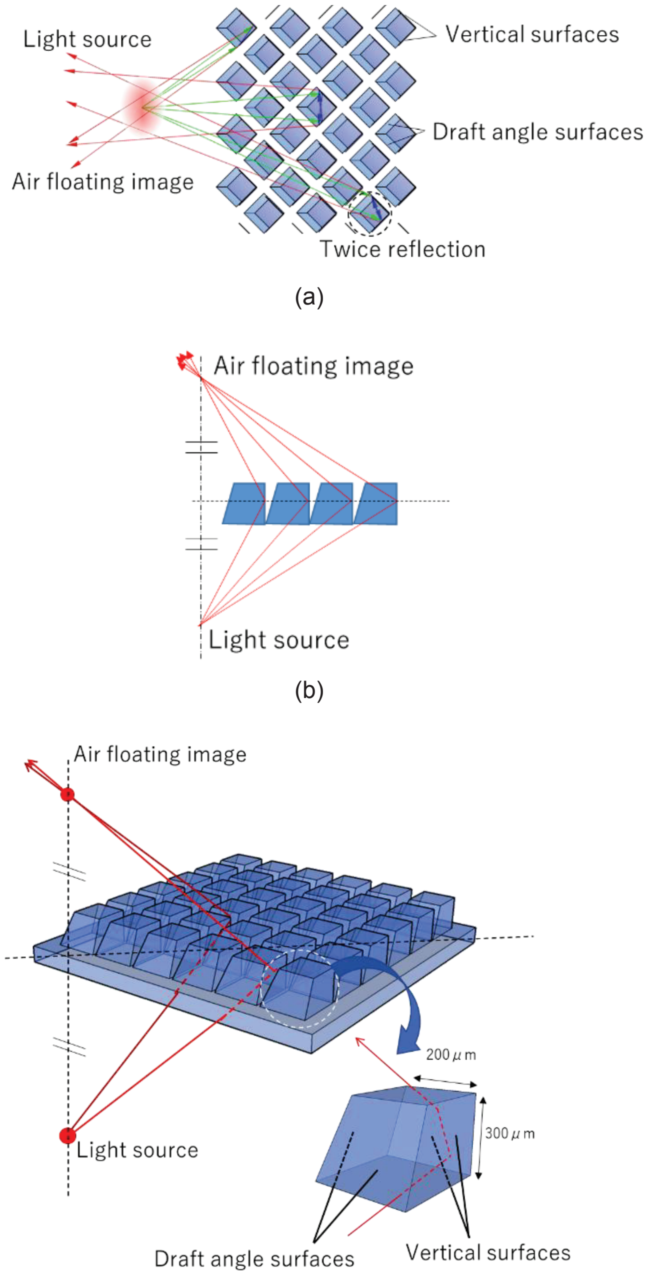


Fig. 1. Schematic illustration of the transparent material type DCRA and rays.
(a) is top view. (b) is side view. (c) is overhead view with enlarged view of unit optical system.

Some incident rays are reflected twice in the pillar by total internal reflection and invert the horizontal component, *i.e.*, retro-reflection in the plane of the DCRA surface, as shown in Fig. 1 (a). On the other hand, vertical component of the incident rays does not invert and path through the DCRA, as shown in Fig. 1 (b). Thinking together, the optical path of the twice-reflected ray is plane-symmetric with respect to the DCRA. Accordingly, an air floating image (real image) of an object is formed at the plane-symmetric point. An observer can see the floating image when the image is viewed obliquely from above.

On the other hand, no reflection (direct passing), once reflection and multiple (three or more times) reflection are observed as stray light, as shown in Fig. 2. Especially, the stray light due to the once reflection is brighter than twice reflected rays, so that it disturbs watch of the air floating image. Separating DCRA from an object can decrease the bad effect of the stray light due to once reflection because the incident angular range for the twice reflection is different from the once reflection, as shown in Fig. 3.

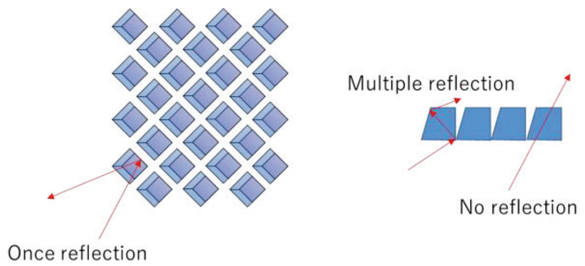


Fig. 2. Stray light caused in DCRA.
Left is top view and right is side view.

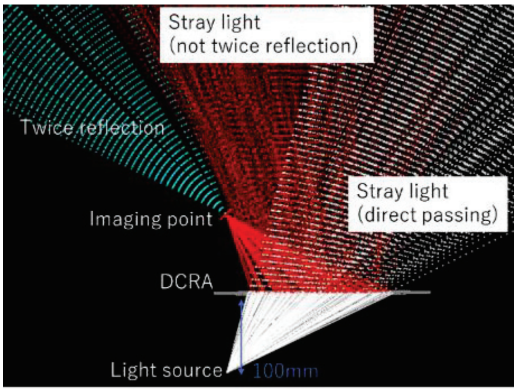


Fig. 3 Side view of DCRA and its ray tracing simulation.
Observation area of twice reflection rays and stray light is separated in this case.

An imaging position formed by the DCRA is plane-symmetric, not depend on a focal length, so that the floating image is not distorted by aberration. Therefore, the air floating image can be seen fixed position in the air regardless of the direction and distance of viewing. However, the air floating image is blurred by diffraction because the rays pass through the transparent pillar with a size of 200μm. This problem between the stray light and blurring is trade-off, so that it is important to arrange DCRA and the light source properly as usage. Thus, DCRA is considered as one of the best air floating image displays when the distance between the floating image and DCRA is short, typically within tens of centimeters.

Another problem is diffuse reflection caused at the groove of the DCRA. When DCRA is seen under a ceiling light, the surface of the DCRA looks white due to the diffuse reflection, as shown in Fig. 4. As the result, contrast of the floating image decreases. It is desirable to reduce the diffuse reflection using a light shield corresponding to the shape of the groove.

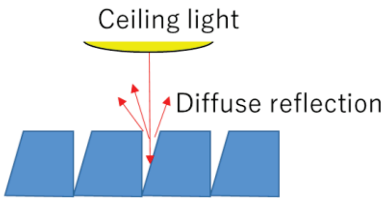


Fig. 4. Diffuse light caused at the groove of the DCRA.

3 RESULT

3.1 Display of an Air Floating Image

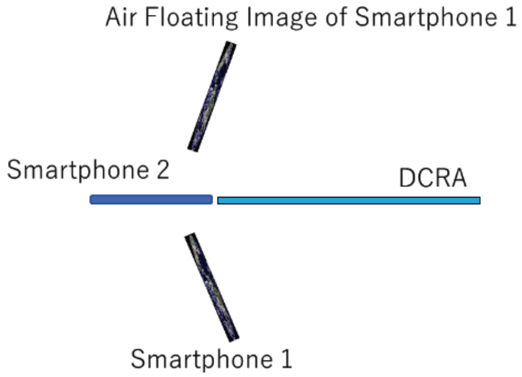
Figure 5 shows an air floating image formed by the DCRA with a light shield to reduce the diffuse reflection. The air floating image was formed without distortion. An effective incident angle for twice reflection is ±15 degrees horizontally from the center and from 30 degrees to 50 degrees vertically. Imaging efficiency is about 13%, so high brightness light source is required when used in a lighting environment. Current maximum size of the DCRA is 150mm x 150mm.

Fig. 5. Air floating image formed by the DCRA.

3.2 Application of an Air Floating Display

Application using the DCRA is relatively easily because the DCRA is a passive optical element and position of a light source is not restricted by focal length. In this paper, three examples of air floating displays using the DCRA are introduced.

The first application using two smartphones is shown in Fig. 6. In this case, the air floating image of smartphone1 appears as if it is displayed from smartphon2. Although this is very simple gimmick, it can be effective spatial presentation.

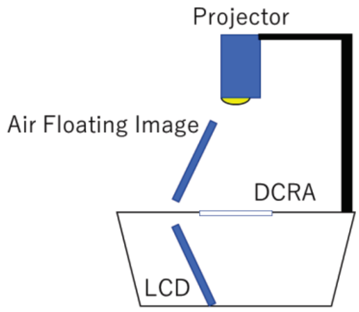


(a)

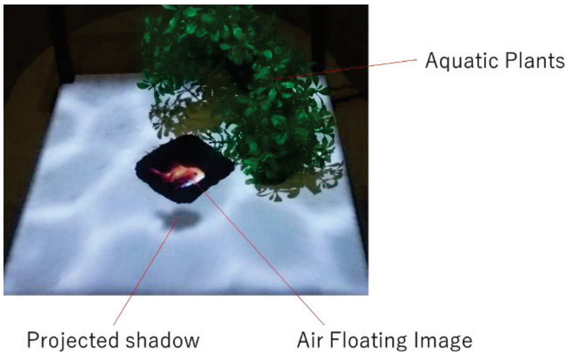
(b)

Fig. 6. Air floating display system using two smartphones
(a) is side view of the arrangement. (b) is picture of the prototype.

Figure 7 shows more art-oriented application that is combined with projection-mapping. The projector arranged above the DCRA projects water surface and the shadow of the fish (air floating image) synchronized with the movement of the fish. By adding the shadow, the effect of air floating image is enhanced.



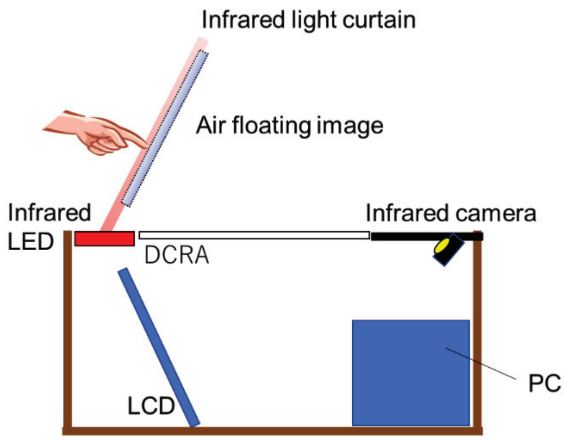
(a)



(b)

Fig. 7. Air floating image with projection mapping.
(a) is side view of the arrangement. (b) is picture of the prototype.

As a practical application example, we developed AIRIA (AIR InteRactive display), that is a non-contact touch display using an air floating image as shown in Fig. 8. User's finger position is detected by infrared LED and camera system. Depth of the surface of the air floating image is plane-symmetric of LCD with respect to the DCRA. Therefore, by matching the position of infrared light curtain and the air floating image, user's touch can be detected when the camera capture user's finger illuminated by the infrared light.



(a)

(b)

Fig. 8. Floating Touch Display.

(a) is side view of the arrangement. (b) is picture of the prototype.

4 CONCLUSIONS

In this paper, basic principle and applications of DCRA were introduced. DCRA forms a distortion-free floating image that can be seen fixed positions in the air regardless of the direction and distance of viewing. Since DCRA is passive imaging device, it is applicable to various types of display systems. As application cases, air floating display system using two smartphones, air floating image with projection mapping and AIRIA were introduced.

DCRA can be manufactured with a transparent material, such as PMMA, by thermal nanoimprint. Therefore, the DCRA has potential of mass production and wide range application. However, at the moment, market of the air floating image display stays in exhibition demonstration. For market expansion, we are working to reduce manufacturing costs and improve optical performance such as light efficiency. Moreover, upsizing of the DCRA and expansion of observation angle are important future works.

REFERENCES

[1] S. Maekawa, K. Nitta, and O. Matoba, “Transmissive Optical Imaging Device with Micromirror Array,” Proc. SPIE 6392, 63920E (2006).

[2] S. Maekawa, K. Nitta, and O. Matoba, "Advances in Passive Imaging Elements with Micromirror Array," Proc. SPIE 6803, 68030B (2008).

[3] D. Miyazaki, N. Hirano, Y. Maeda, S. Yamamoto, T. Mukai, and S. Maekawa, “Floating volumetric image formation using a dihedral corner reflector array device,” Appl. Opt. 52(1), A281-A289 (2013).

[4] H. Yamamoto and S. Suyama, “Aerial 3D LED display by use of retroreflective sheeting,” Proc. SPIE 8648, 86480Q (2013).

[5] S. Iwasawa, M. Kawakita, S. Yano, M. Sakai, Y. Haino, M. Sato, and N. Inoue, “A 200-Inch 3D-Glasses-Free High-Definition Projection Display,” SMPTE Conf. Proc. 2011, pp. 1-3 (2011).

[6] S. Yoshida, “fVisiOn: Glasses-free Tabletop 3-D Display - Its Design Concept and Prototype,” 2011 Digital Holography (DH) and Three Dimensional (3-D) Imaging Meeting, Tokyo, 9-11 May, DTuA1 (2011).

[7] M. Imura, A. Yagi, Y. Kuroda, O. Oshiro: Multi-Viewpoint Interactive Fog Display. International Conference on Artificial Reality and Telexistence, p.170, (2011).

[8] H. Ishikawa, H. Watanabe, S. Aoki, H. Saito, S. Shimada, M. Kakehata, Y. Tsukada, H. Kimura, “Surface representation of 3D objects for aerial 3D display,” Proc. SPIE 7863, 78630X (2011).