Large Air Floating Image Device and Application to Non-Contact User Interface

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ABSTRACT

An air floating image device based on a dihedral corner reflector array is 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 non-contact sensor.

1 INTRODUCTION

An air floating image display have appeared frequently in science fiction movies, and their realization and practical application have been expected. In recent years, technological development of air floating image displays using imaging optics has progressed [1-4], and one of them is based on retro-reflection by micromirror array. 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 with the naked eye, having a high sense of reality without distortion, and being able to display existing video content as it is in full color as an air floating image.

Parity Innovations Co. Ltd. has developed a dihedral corner reflector array (DCRA) [1, 2], product name “Parity mirror”, that can be mass-produced micromirror array based optical imaging device. Furthermore, a non-contact user interface, such as an air floating switch and an air floating touch display, has been developed as an application product using DCRA. This technology is attracting a lot of attention because it can prevent contact infections in infectious diseases such as COVID-19, that the virus can survive for a long time on the surface of an object [5].

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.

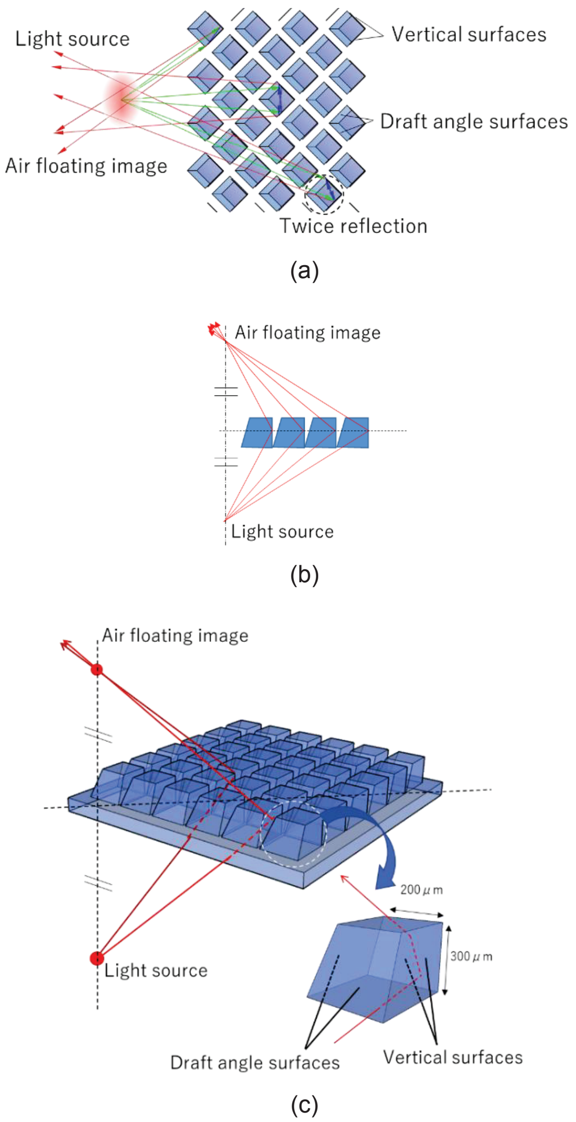


Fig. 1. Schematic illustration of the transparent material type DCRA and rays.
(a) is top view. (b) is side view. (c) is overhead view with enlarged view of unit optical system.

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.

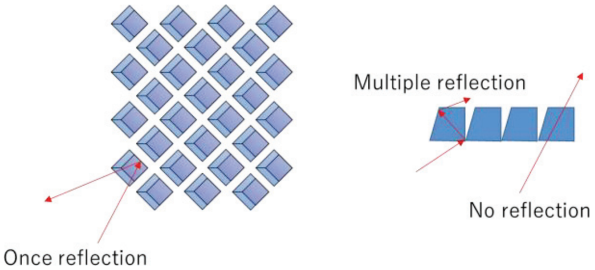


Fig. 2. Stray light caused in DCRA.
Left is top view and right is side view.

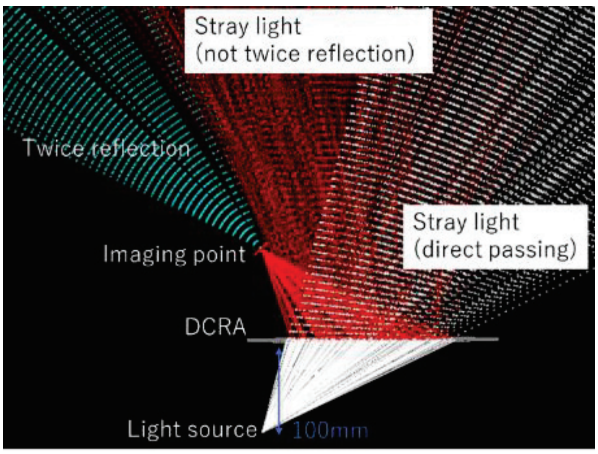


Fig. 3 Side view of DCRA and its ray tracing simulation.
Observation area of twice reflection rays and stray light is separated in this case.

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.

Another problem is diffuse reflection that causes a decrease in contrast. When an air floating image is seen under lighting environment such as a ceiling light, the surface of the DCRA looks white due to the diffuse reflection at the groove of the DCRA, as shown in Fig. 4(a). As the result, contrast of the floating image decreases as shown in Fig. 4(b). The diffuse reflection can be reduced by shading corresponding to the shape of the groove as shown in Fig. 5.

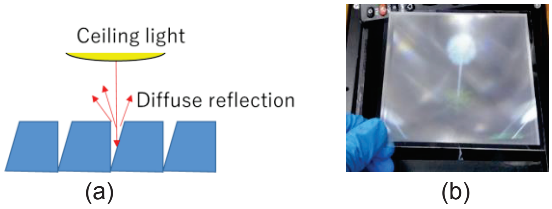


Fig. 4. Diffuse reflection caused at the groove of the DCRA.
(a) is a schematic diagram. (b) is a display result. The dandelion is an air floating image.

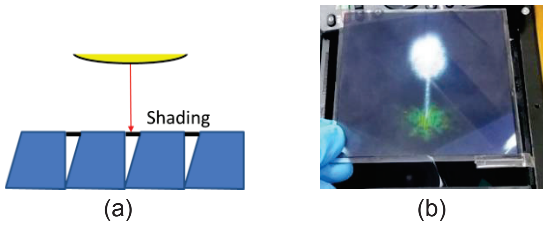


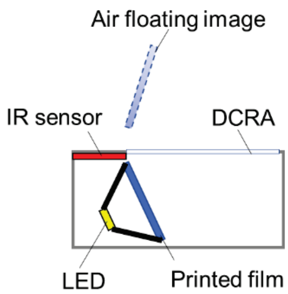
Fig. 5. Shading treatment to DCRA to reduce the diffuse reflection.
(a) is a schematic diagram. (b) is a display result. The contrast of the air floating image is improved by shading.

DCRA can be manufactured by thermal nanoimprint using a metal stamper made by nano processing machine. Figure 6 shows the current maximum size of 300mm square DCRA with the shading. The material is PMMA. An effective incident angle for twice reflection is ±15 degrees horizontally from the center and from 20 degrees to 50 degrees vertically. Imaging efficiency is about 13%, so it is desirable to use a high brightness light source, especially under lighting environment.

Fig. 6. 300mm square DCRA
The left is a 300 mm square size, and the right is a conventional 150 mm square size.

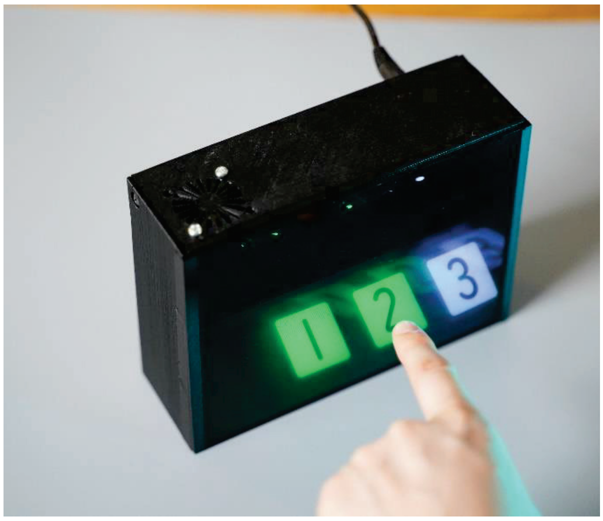
3 NON-CONTACT USER INTERFACE

A non-contact user interface can be developed using DCRA with a non-contact sensor, such as an infrared sensor, an ultrasonic sensor and a camera system. Figure 7 shows the non-contact switch devices series named “AiR Switch”. Since DCRA has no optical axis or center, it can be cut to any size. In the case of Fig. 7 (b) and (c), DCRA was cut to 50mm square and 150mm x 75mm respectively. An infrared Time-of-Flight sensor was used as the non-contact sensor. An LED backlight and printed film were used as the light source.



(a)

(b)

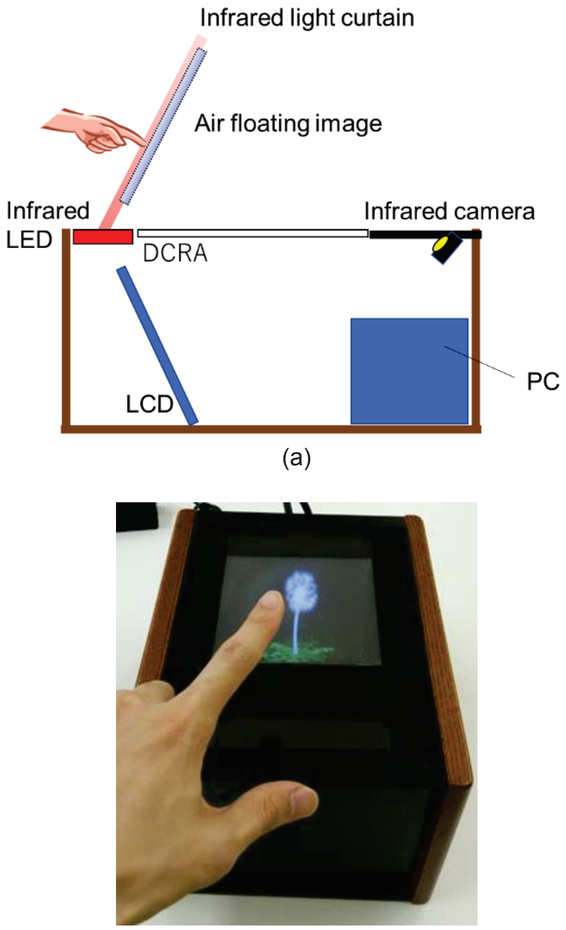


(c)

Fig. 7. AiR Switch.
(a) is a schematic side sectional view, (b) is a one-button type, and (c) is a multi-button type arranged horizontally.

For example, by connecting AiR Switch to a desk light, the light can be turned on and off in a non-contact manner. In addition, by incorporating it into a building or device in advance, it is possible to operate the number of floors in elevator or a toilet flush button without physical contact. It is considered that replacing the operation device in public space with AiR Switch is effective to prevent contact infections in infectious diseases such as COVID-19.

As another example, we developed AIRIA (AIR InteRactive display) that is a non-contact touch display using an air floating image and a camera system that enables more complicated non-contact operations. As shown in Fig. 8, user’s finger is illuminated by the infrared light curtain and detected by the infrared camera. The position of the finger is calculated by image processing. Depth of the air floating image is plane-symmetric of LCD with respect to the DCRA. Therefore, by matching the depth of the infrared light curtain and the air floating image, contact judgement can be detected with a single camera.



(a)

(b)

Fig. 8. AIRIA.
(a) is side view of the arrangement. (b) is picture of the prototype.

4 CONCLUSIONS

In this paper, basic principles 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 Switch and AIRIA were introduced as examples of non-contact user interfaces.

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. 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.

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