Spatial Image Display using Double-sided Lenticular or Fly's Eye Lens Sheets

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Abstract: In this paper, a novel spatial image display system is described in which the 3D image of a real object is displayed as if it were floating at a position considerably distant from the screen. In our system, double-sided lenticular or fly's eye lens sheets are used. The light rays emitted from a point on the object are refracted by the double-sided lenses sheets and meet together in the space. Therefore a real image that appears to be floating in the air is formed. Since our system can be produced with only a single material like transparent plastic and no corner mirrors are necessary, it is suitable for mass-production with metal molds, and therefore, it is much more inexpensive than existing technologies.

1 INTRODUCTION

Autostereoscopic display systems that use a parallax barrier, a lenticular lens, or a fly's eye lens have already been widely used in various fields and uses, such as for 3D digital photo frames, a 3D portable game machine, etc. In some of these systems, a flat panel display such as an LCD is covered with a parallax barrier or a lens sheet (Yanaka et al., 2009); (Kira et al., 2012). However, in such systems, a 3D image is usually displayed at a position near the screen since the degree of pop out is not large. The 3D image becomes blurred when it is formed far away from the display mainly because the pixel size of the LCD is not small enough, and hence, the density of the rays becomes coarse rapidly when the rays become distant from the screen.

In contrast, there is a somewhat similar but essentially different technology called "spatial image display" in which a 3D image of a real object is displayed as if it were floating at a position considerably distant from the screen. Basically, it is a passive device consisting of optical components such as lenses and mirrors only.

2 SPATIAL IMAGE DISPLAY

In a spatial image display, a real object can be used as the object to be displayed, and users perceive that the object is floating in the air because a real image of the object is in front of them.

However, caution is required to prevent the reversal of depth. To prevent this reversal, an LCD can be used as the real object. The real image displayed on the LCD is visible in the air, and reversal of depth does not occur since the LCD screen is two-dimensional in nature.

Therefore, this kind of technology is suitable for making use of the space where the virtual space and real space overlap in AR or MR or for attracting the attention of people with digital signage.

Various systems related to this system are also known. For example, it has been known for many years that a real image displayed with one big convex lens can float images of 3D objects in the air. Here, the convex lens can be substituted by a concave mirror or a Fresnel lens. Recently, a system that uses a Fresnel mirror instead of a convex lens was proposed (Yanaka and Yoda, 2011); (Yanaka et al., 2012).

Systems that use a special optical component such as an array of corner reflectors have also been proposed. A system that uses a Transmissive Mirror Device (TMD), which is a two-dimensional array of micro dihedral corner reflectors, was developed by the National Institute of Information and Communications Technology (NICT) in Japan (Maekawa, 2009.). The principle of Askanet's Aerial Imaging Plate^{TM} (Asukanet, 2012) is similar to it, but their manufacturing process is considerably

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different. In both cases, however, the manufacturing cost is very high because it is currently difficult to make many minute mirrors with high precision.

Therefore, we propose a novel and considerably inexpensive system in which no corner reflectors are used.

3 METHOD

We developed a system in which an image is displayed as if it were floating in the air by using a double-sided lenticular lens sheet or fly's eye lens sheet whose thickness is approximately twice the focal length of the tiny cylindrical or convex lenses on both sides of the sheet.

Figure 1 (a) shows a perspective view of our system. An object is put on one side of the double-sided lenticular lens sheet. When the object is observed from the other side, it appears as if it were floating. Figure 1 (b) shows how light rays pass in and around the lens sheet. The light emitted from a point on the object is refracted by the cylindrical lenses on the other side, and a real image of the object is formed around the focal point, which is approximately at the center of the lenticular lens sheet. Since there is no diffuser there, the rays go through the real image without being diffused, and they are refracted by the cylindrical lenses on this side of the lens sheet. The refracted rays meet together in the space. Therefore a real image that appears to be floating in the air is formed.

Figures 2 (a) and (b) show the relation between a curvature radius and a focal length of a convex piece, where n denotes the refractive index of the material, r denotes the curvature radius, f_1 denotes the focal length inside of the lens, and f_2 denotes the focal length outside of the lens.

It should be noted that f_1 is larger than f_2 as follows.

In Fig. 2 (a), the following equality holds.

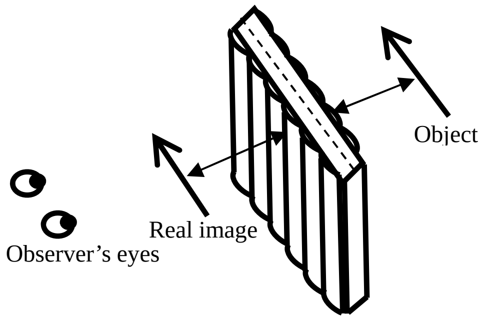
$$X = r\sin\theta_1 = f_1 \sin(\theta_1 - \theta_2),$$

and according to Snell's law,

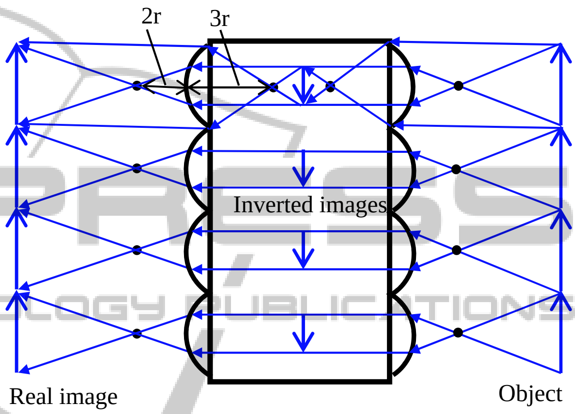
$$\frac{\sin\theta_2}{\sin\theta_1} = \frac{1}{n}$$

Assuming that the material of the lens is acrylic with n = 1.5,

$$f_1 = \frac{r\theta_1}{\theta_1 - \theta_2} = 3r$$

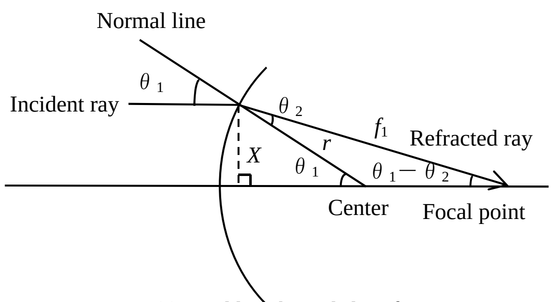


(a) Perspective view of our system.

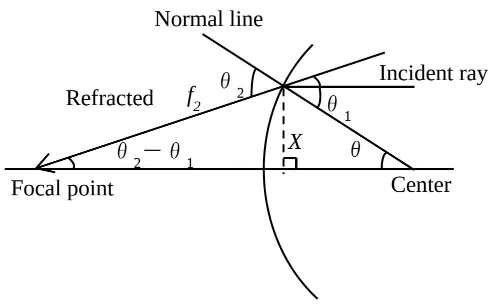


(b) Optical path of incident and refraction light.

Figure 1: Our system's framework.



(a) Focal length inside lens f_1



(a) Focal length outside lens f_2

Figure 2: Relation between a curvature radius and a focal length of a convex piece.

In Fig. 2 (b), the following equality holds.

$$X = r\sin\theta_1 = f_2\sin(\theta_2 - \theta_1),$$

and according to Snell's law,

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{1}{n}$$

Assuming that the material of the lens is acrylic with $n = 1.5$,

$$f_2 = \frac{r\theta_1}{\theta_2 - \theta_1} = 2r$$

4 EXPERIMENTS AND RESULTS

4.1 Double-Sided Lenticular Lens

Four kinds of single-sided lenticular lenses, shown in Table 1, were used in the experiments. We made a double-sided lenticular lens by pasting two single-sided lenticular lenses back-to-back. When a real object such as a beckoning cat was put on one side of the lens and observed from the other side, the object looked as it if were floating on the observer side of the lens, as shown in Figure 3.

Figure 3: Double-sided lenticular lens in which two of the same single-sided lenticular lenses were pasted back-to-back.

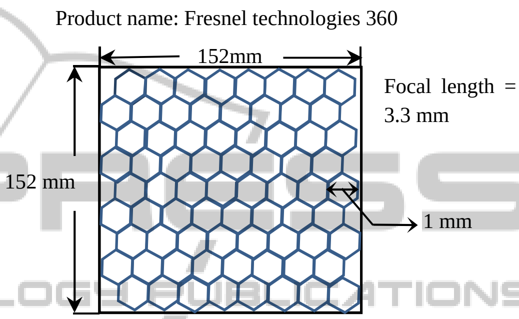
Table1: Specifications of lenticular lenses.

LPI	Thickness (mm)	Effect	Viewing angle (degree)	Viewing distance (m)	Material
40 (3D)	2.08	3D	25	1 ~ 4.5	PET-G
40	0.83	2D/3D	49	1 ~ 4.5	Polyester
60 (3D)	1.2	3D	26	0.3 ~ 3	PET-G
60	0.43	2D	74	0.3 ~ 3	PET-A

4.2 Double-sided Fly's Eye Lens

A double-sided fly's eye lens can be used instead of a double-sided lenticular lens. In this case, not only horizontal but also vertical parallax can be obtained.

We conducted experiments by using commercially available fly's eye lenses, shown in Figure 4, and an excellent spatial display could be produced. In the system that uses a lenticular lens, stereoscopy might be lost when the head is tilted. In the system that uses a fly's eye lens, such worries are unnecessary.



(a) Specifications of fly's eye lens.

(b) Experimental result.

Figure 4: Double-sided fly's eye lens in which two of the same single-sided fly's eye lenses were pasted back-to-back.

4.3 Two Single-sided Lens

It was revealed that two single-sided lens sheets placed apart at twice the focal length as shown in Figure 5 can be used together instead of a double-sided lens sheet.

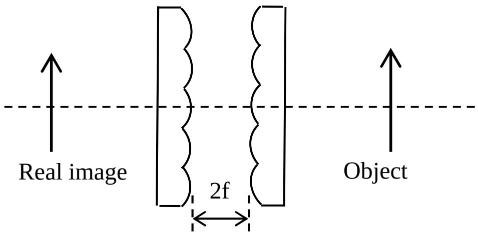


Figure 5: Alternative way of using two single-sided lenticular lenses.

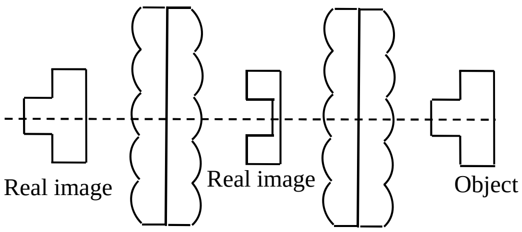
4.4 Combining Lens Sheets with Different Viewing Angles

It is also possible to combine lens sheets that have different viewing angles. Figure 6 shows an example in which a lenticular lens with a viewing angle of 49 degrees and another lenticular lens with a viewing angle of 25 degrees are pasted back-to-back. In this case, a clearer 3D image with a large degree of pop out can be seen when the side with the wide viewing angle is on the object side and near the object.

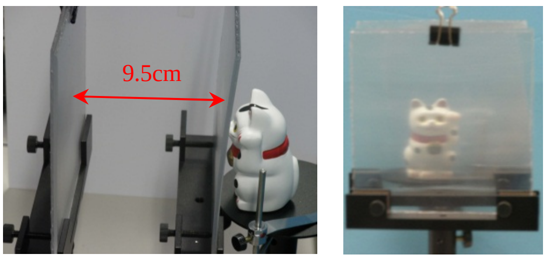
Figure 6: Double-sided lenticular lens in which two different single-sided lenticular lenses were pasted back-to-back. Object side: 49 degrees, the viewer's side: 25 degrees.

4.5 Depth Correction using Two Double-sided Lens Sheets

As already stated, depth is reversed in this system. However, it can be corrected by using two double-sided lens sheets sequentially as shown in Figures 7 (a) and (b).



(a) Principle of depth correction.



(b) Experimental results.

Figure 7: Depth correction using two double-sided lenticular lens sheets.

5 CONCLUSIONS

We proposed a novel spatial image display system that uses relatively inexpensive double-sided lenticular or fry's eye lenses, and it was revealed that a real floating image of a real object can be displayed, although the depth is reversed. This problem can be solved by using two double-sided lens sheets sequentially. However, when the object is a two-dimensional object such as a PC screen, reversal of depth does not matter because its real image made with this equipment is also two-dimensional. If GUI components such as buttons or menus are displayed on the PC screen, they will look like they were floating too. Since the position of a user's hand and fingers can be obtained by using other technologies such as a television camera or the Microsoft Kinect, the user can do operations such as pushing a button or moving a cursor without touching the physical screen. This is no more than one example among many. This inexpensive device is considered to hold the power to change human-machine interfaces.

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