Poster: Toward an Interactive Box-shaped 3D Display: Study of the Requirements for Wide Field of View

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Abstract

We propose a graspable box-shaped 3D display as a communication tool that allows multiple users to share and naturally interact with 3D images in face-to-face collaborative tasks.

We envision an auto-stereoscopic 3D display featuring glasses-free and multi-viewpoint operation. Users should be able to view multiple faces in the box-shaped display simultaneously and from any direction. We employ the integral photography (IP) method for this purpose.

In this paper, we first analyze the requirements for an IP lens allowing simultaneous multi-face viewing of 3D images in such a display. Consequently, we find that a mininum 120-degree field of view is necessary. Then, we design and prototype an IP lens that provides such a wide field of view. Visual inspection of the generated 3D images confirm the possibility of simultaneous multiple-face viewing with the proposed display.

Index Terms: H.5.1 [Multimedia Information Systems]: Artificial, augmented, and virtual realities; H.5.2 [User Interfaces] H.3.7 [Three-Dimensional Graphics and Realism]

1 Introduction

Collaboration among multiple users requires easy access to shared information and natural human-object interactions. In the case of face-to-face collaborations, users often rely on physical objects to support their discussion of ideas. Direct manipulation of physical objects is a natural human skill that is commonly used in conjunction with verbal and gestural descriptions.

Computer-supported collaborative work enhances users' discussions by introducing virtual objects and making digital information accessible via a human-computer interface. Tangible user interfaces promise to leverage our natural object manipulation skills by using physical artifacts as representations and controls for digital information. Interaction is unmediated and intuitive, leading to "direct engagement [2][9]."

In this regard, we propose a graspable box-shaped 3D display that perfectly matches these ideas (figure 1). Here, input and output occur in the same space, thus providing a natural interaction [10]. Cube-shaped devices seem to provide good affordance for natural interaction [7]. Other cubic displays employing 2D screens have been proposed before, but they provide only a single-viewpoint correct perspective and lack the sense of image depth and binocular parallax clues [5]; other systems require head-tracking devices and glasses for single-viewpoint stereo viewing [4][8].

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Figure 1: Overview of a multi-viewpoint box-shaped 3D display

On the other hand, visual representation of digital information gives the user essential feedback to understand what effect his/her interaction has on the data. Auto-stereoscopic displays allow multiple users to naturally view 3D images with the sense of image depth and binocular parallax without the need for glasses or head-tracking devices. We decided to use integral photography (IP) [6] as our auto-stereoscopic method. IP utilizes an array of tightly packed small lenses to capture and display different perspective views of a scene to provide compelling 3D images. However, IP lens arrays have only a narrow field of view, since they have been designed for single-face displays[1].

The following section analyzes the requirements of multi-face viewing IP lenses for our box-shaped 3D display. We designed and prototyped an IP lens consisting of two lenses that provide a wide field of view. Visual inspection of the generated 3D images confirmed the possibility of simultaneous multi-face viewing with the proposed display.

2 Simultaneous Multi-face Viewing IP Lens Design

2.1 IP Lens' Field of View Requirements

Given that our box-shaped display is to be viewed from any direction, then each IP lens should be able to modulate light rays at an angle of at least 2θ, as shown in figure 2.

An extreme case occurs when simultaneously viewing three faces in the display. Let D be the viewing distance, then the viewpoint becomes $\vec{e} = D/\sqrt{3}(1,1,1)$. Also, let B be the size of one face and $\vec{c} = (0,0,B/2)$ be the center of the upper face F with normal $\vec{n} = (0,0,1)$, then the above θ is the angle between the viewing vector $\vec{v} = \vec{e} - \vec{c}$ and the normal $\vec{n}$. For D=400 mm and B=72 mm, θ becomes 59.2 degrees.

The type of lens array generally used in IP can be considered a planar array of several plano-convex lens of pitch size p tightly packed together.

If f is the focal length, p the pitch, and 2θ the field of view of the lens, as shown in figure 2, then $p/2 = f \tan\theta$. Now, if n is the index of refraction and r the radius of curvature of the lens, the lens maker's formula states that $n = r/f + 1$. For manufacturing purposes, r has to be greater than or equal to $p/2$, which implies

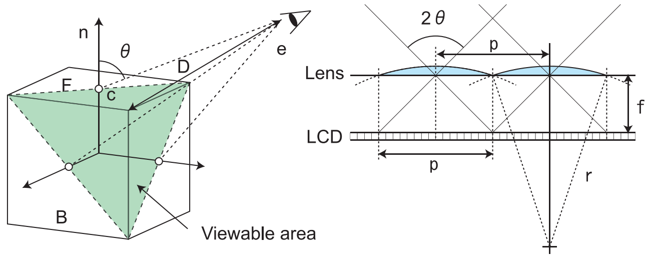

Figure 2: IP Lens' field of view requirements

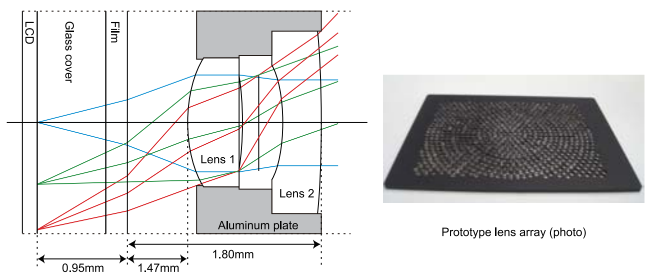

Figure 3: Prototype of our IP lens array

that $n \geq p/(2f)+1 = \tan\theta + 1$. For θ=60degrees, then n becomes 2.7.

Given that the optical glass commonly used in commercial IP lenses has an index of refraction, n, in the range of 1.5∼1.7, it is clear that a commercially available IP lens cannot be used in our box-shaped 3D display.

2.2 Proposed IP Lens Array

In order to achieve a minimum 120-degree field of view, we designed and implemented an IP lens composed of two lenses.

Each IP lens consists of one bi-convex lens and one convex-concave lens arranged, as shown in figure 3, in front of the LCD on the left. The IP lenses are mounted inside holes made on a 1.8-mm-thick black-painted aluminium plate. The holes have a radius of 2.0 mm and are arranged in a circular layout to avoid or minimize image cross-talk between the wide-angle lenses. The IP lens separation was fixed at 2.25 mm by setting each IP lens to cover a 20x20-pixel area of the LCD display used in our experiments. The IP lens' focal length, aperture and other parameters were optimized for image quality, and the LCD's glass and film were taken into account in the calculations.

3 3D Images from our prototyped IP lens array

We implemented the IP image-rendering algorithm proposed by Halle [3] using the OpenGL library. Each IP elemental image is generated by using a virtual camera with a 120-degree field of view, moving its center of projection to each IP lens location, and rendering the global scene. The final IP image is then composed from these IP elemental images.

The virtual objects scene consists of a sphere next to a cone with a torus on top. We used a notebook PC connected to a 3.5-inch LCD display with a 640×RGB×480 resolution to display the IP image.

Example results of 3D images displayed by our prototyped IP lens array are shown in figure 4 from three different viewpoints of the display. The picture in the center was taken directly from above, along the display's face normal, while the left and right pictures were taken from the side, ±60 degrees from the face normal.

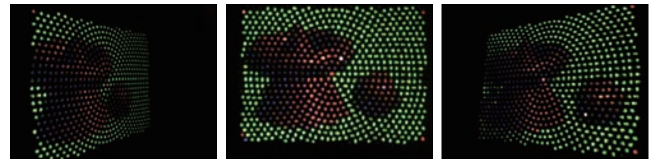

Figure 4: Displaying results: Virtual scene from different viewpoints

The distance between the IP lens and the digital camera used to take these pictures was 400 mm. Note the horizontal parallax by comparing the space separation between the cone and the sphere in each of the three views presented. The prototyped 120-degree field of view IP lens well serves the purpose of this research, that is, building a multi-face box-shaped 3D display.

However, our prototyped IP lens allows only partial viewing of three faces simultaneously (see "viewable area" in figure 3). We have already analyzed the solution to this problem and are now designing and prototyping an extra lens [10].

4 Conclusions and Future Work

We have analyzed the requirements for an IP lens allowing simultaneous multi-face 3D viewing for use in our proposed compact and graspable box-shaped 3D display. Based on this, we designed and prototyped an IP lens and visually confirmed that it provides a 120-degree field of view.

Future work remains to improve image quality, achieve complete simultaneous multi-face viewing, and build the box-shaped 3D display with all six of its faces. Furthermore, after adding sensors, we need to consider concrete examples of new interaction methods that can be applied to such a display.

We would like to see our graspable 3D display used as a natural substitute for real objects in face-to-face discussions among multiple users. Users would feel as if they were holding a real 3D object that they could manipulate, point at, and possibly change or replace with another object via simple interaction gestures. We foresee applications for object design and modelling, education, and games.

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