Spherical Full-parallax Light-field Display Using Ball of Fly-eye Mirror

Hiroaki Yano
Nagaoka University of Technology
Nagaoka, Nigata pref., Japan
s153214@stn.nagaokaut.ac.jp

Tomohiro Yendo
Nagaoka University of Technology
Japan
yendo@nagaokaut.ac.jp

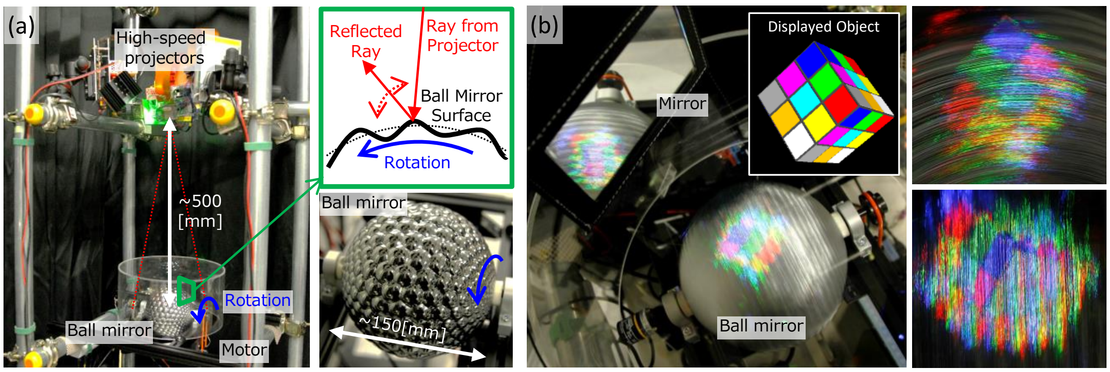

Figure 1: (a) Overview of proposed system. (b) A 3D image shown by prototype.

ABSTRACT

We present an optical system design for a 3D display that is spherical, full-parallax, and occlusion-capable with a wide viewing zone and no head tracking. The proposed system provides a new approach for the 3D display and thereby addresses limitations of the conventional light-field display structure. Specifically, a spherical full-parallax light-field display is difficult to achieve because it is challenging to curve the conventional structure of the light-field displays. The key elements of the system are a specially designed ball mirror and a high-speed projector. The ball mirror uniaxially rotates and reflects rays from the projector to various angles. The intensities of these rays are controlled by the projector. Rays from a virtual object inside the ball mirror are reconstructed, and the system acts as a light-field display based on the time-division multiplexing method. We implemented this ball mirror by 3D printing and metal plating. The prototype successfully displays a 3D image and the system feasibility is confirmed. Our system is thus suitable for displaying 3D images to many viewers simultaneously and it can be effectively employed as in art or advertisement installation.

CCS CONCEPTS

• **Human-centered computing** → **Displays and imagers**; • **Hardware** → **Displays and imagers**; Emerging optical and photonic technologies; • **Applied computing** → *Media arts*;

SIGGRAPH '18 Emerging Technologies, August 12-16, 2018, Vancouver, BC, Canada

ACM ISBN 978-1-4503-5810-1/18/08.
https://doi.org/10.1145/3214907.3214917

KEYWORDS

Light-field display, Full-parallax, Spherical display

ACM Reference Format:
Hiroaki Yano and Tomohiro Yendo. 2018. Spherical Full-parallax Light-field Display Using Ball of Fly-eye Mirror. In *Proceedings of SIGGRAPH '18 Emerging Technologies.* ACM, New York, NY, USA, 2 pages. https://doi.org/10.1145/3214907.3214917

1 INTRODUCTION

Various types of 3D displays have been actively studied. Because 3D images are more attractive than 2D images, glasses-free 3D displays are expected to be particularly used as digital signage. The wider the viewing zone is, the more of the scene viewers can simultaneously observe. Thus, spherical or cylindrical displays that have a wider viewing zone than flat ones have an advantage in digital signage use. In addition, a sphere is a suitable 3D display shape for observing a displayed object from various directions.

Some spherical 3D displays or wide-viewing-zone 3D displays were proposed. Spheree [Ferreira et al. 2014] is a 3D display that employs a sphere-shaped rear projection screen and head tracking. In this method, it is difficult to show a 3D image to multiple viewers. On the other hand, Perspecta [Favalora et al. 2002] is a volumetric 3D display that can show a 3D image to multiple viewers. However, it cannot feature occlusion effects because volumetric displays cannot block light from the light point behind the displayed object. The occlusion effect is an optical effect by which objects behind an opaque object cannot be viewed because the light is blocked.

The light-field display is a 3D display achieved by reconstructing rays from a displayed object. Complicated optical effects, such as occlusion effects or refraction, can be achieved by reconstructing rays from a displayed scene. A typical example of the display is integral imaging using a lens array [Lippmann 1908]. Because this method requires high-density lenses and pixels, a curved display, such as a spherical one, is difficult to achieve. The light-field display using a high-speed rotating mirror has a special reflection property [Jones et al. 2007] and can show a 3D image for every angle around the display. This optical system can feature the motion parallax effect in only the horizontal direction. The vertical parallax is achieved by using head tracking. However, this method is limited under the condition of no multiple viewpoints being located at the same horizontal direction from the display. Some light-field displays are not capable of achieving the vertical parallax; a correct 3D image cannot be viewed from the area out of the assumed vertical position. A display that is capable of achieving both vertical and horizontal parallax is called a full-parallax display.

The purpose of this study is to design an optical system that achieves the full-parallax spherical light-field display that multiple viewers can simultaneously view and that features the occlusion effect without head tracking.

2 SYSTEM OVERVIEW

Our eyes ordinarily receive light reflected on real 3D objects. The received rays differ depending on the eye position. This difference engenders the parallax experience and comprises the basis of our depth cues. The light-field display is basically aimed to reconstruct these rays from a surface in space. Considering a surface located between viewpoints and the object, the colors of rays intersecting on it differ according to the position where the rays intersect and the ray directions. Conventional 2D displays change color according to the ray position on the display only. Light-field displays can control color according to the ray position and direction. This capability changes observations according to the viewpoint position and it produces parallax. Accordingly, the light-field display can display 3D objects.

The proposed system, shown in Figure 1 (a), consists of a high-speed projector and a rotating ball mirror. Rays emitted by a projector reflect on the ball mirror. All normal vectors of a perfectly spherical surface radiate from its center. On the other hand, the ball mirror has an uneven surface and its normal vector differs depending on the position. The normal vector varies in a specific range α° from the sphere normal. Considering a single ray, the reflection direction of the ray is altered by rotating the ball mirror. By changing the intensity of all rays with the projector, each ray intensity differs according to the ray direction and the location where the ray is reflected. Thus, the spherical light-field display is achieved. The ball mirror rotates at an adequate speed to prevent display flickering.

The range of the ray scanning and the ball mirror diameter define the volume of the display area. Figure 2 shows rays emitted by a projector and reflected by the rotating ball mirror of α=20° and 60°. Because the 3D image is reconstructed by the reflected rays in the case of the proposed method, the expected display area is roughly drawn using extended lines in opposite directions of the reflected rays. The wider the range α is, the larger is the display area that is achieved.

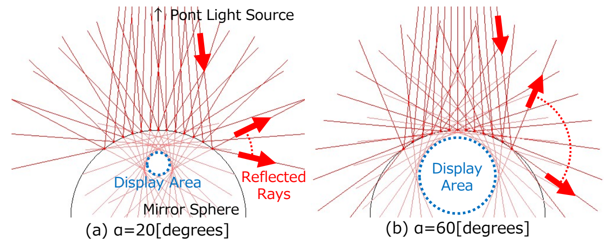

Figure 2: Rays from a point light source reflected on the ball mirror that has a modulated normal in the range of α. The display area in the system is roughly drawn by extended lines of rays.

Controlling the ray intensity corresponds to changing the projected image by the high-speed projector. Thus, ray direction resolution is limited by the number of projection frames per rotation. The projection image is created based on the ray tracing method [Appel 1968].

3 CONCLUSIONS AND FUTURE WORK

Generally, spherical displays have a wide viewing zone and are suitable for the simultaneous display to many viewers. However, a glasses-free 3D display is expected to be used as digital signage. We herein proposed an optical system design for a full-parallax spherical light-field display based on the time-division multiplexing method. The system prototype was developed and it successfully displayed a full-parallax image. The proposed system offers features that are distinct from existing systems that make it suitable for specific uses, such as a digital signage and art exhibitions.

The interactive display based on the proposed system is suitable for group work that utilizes 3D graphics. The real-time rendering, which remains to be achieved, is necessary for interactive use. Improvement of the projection image rendering algorithm will be addressed in future work.

ACKNOWLEDGMENTS

This work was supported by JSPS KAKENHI Grant Numbers JP17H01776, JP16K12475.

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