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Light field display using wavelength division multiplexing

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Abstract

We propose a large screen 3D display which enables multiple viewers to see simultaneously without special glasses. In prior researches, methods of using a projector array or a swinging screen were proposed. However, the former has difficulty in installing and adjusting a large number of projectors and the latter cases occurrence of vibration and noise because of the mechanical motion of the screen. Our proposed display consists of a wavelength modulation projector and a spectroscopic screen. The screen shows images of which color depends on viewing points. The projector projects binary images to the screen in time-division according to wavelength of projection light. The wavelength of the light changes at high-speed with time. Therefore, the system can show 3D images to multiple viewers simultaneously by projecting proper images according to each viewing points. The installation of the display is easy and vibration or noise are not occurred because only one projector is used and the screen has no mechanical motion. We conducted simulation and confirmed that the proposed display can show 3D images to multiple viewers simultaneously.

Introduction

Recently, various types of 3D displays have been studied actively. Because 3D images attract interest and attention of people compared with 2D images, 3D display is effective in advertisement and exhibition. In such applications, a large screen 3D display which enables multiple viewers to see 3D images simultaneously without special glasses is preferable.

In prior research, a 3D display using high-speed rotating screen which has special reflection characteristic was proposed [1]. This display enables viewers to see 3D image with wide viewing zone without special glasses. However, it is difficult to enlarge the screen because of high-speed rotating screen. On the other hand, a 3D display using multiple projectors realized large screen [2]. However, there is difficulty in installing and adjusting the system because many projectors are used to show 3D image. A 3D display using swinging screen realized large screen with only one projector [3]. This display uses time-division projection and the screen has mechanical motion to scan reflection angle of light from the projector. Therefore, there is a problem of vibration and noise.

In summary, there are few large 3D display which enables multiple viewers to see 3D images simultaneously without special glasses presently. Also they have some problems such as difficulty in installing, vibration, and noise.

In this paper, we propose a new large screen 3D display using wavelength division multiplexing to solve problems above-mentioned. The proposed display provides 3D images simultaneously for multiple viewers by time-division display based on wavelength division multiplexing. The display consists of one projector and a passive screen. Therefore, the installation of the display is easy and vibration or noise don't occur. Furthermore, the screen can enlarge easily by changing throw ratio of projector. The display has a constraint which it cannot express color of 3D objects because the color of displayed images depends on viewing points. However, it is effective in advertisement and exhibition because images which changes its color according to viewing points can attract interest and attention of people.

Proposed Method

Figure 1. shows a schematic image of the proposed display. The display consists of a spectroscopic screen and a wavelength modulation projector. The screen shows images which of color depends on viewing points by chromatic dispersion. The projector projects binary images to the screen in time-division according to wavelength of projection light. The wavelength of the light changes at high-speed with time. Therefore, the system can show 3D images to multiple viewers simultaneously by projecting proper images according to each wavelength at high-speed.

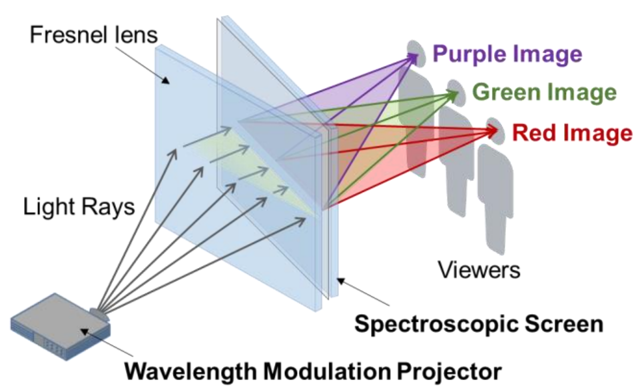

Figure 1. Scheme of proposed display

Spectroscopic Screen

The spectroscopic screen is composed of a transmission diffraction grating, a Fresnel lens, and a vertical diffuser. Parallel light rays from the projector pass through in the order of above and reach viewers. The transmission diffraction grating change direction of incident light rays depending on wavelength of them. The Fresnel lens refracts light rays so that they converge at viewing points. Therefore, the spectroscopic screen can show images of which color depends on viewing points as shown in Figure 2. Also viewers can see images regardless of height because the vertical diffuser diffuses light rays vertically.

Wavelength Modulation Projector

The wavelength modulation projector is composed of white light source, concave diffraction grating, and high-speed projector mainly as shown in Figure 3. The light source emits white light rays to the concave diffraction grating through a slit. The concave diffraction grating converts white light into specific wavelength light and put it into the high-speed projector. Also, the grating changes wavelength of projection light at high speed by its swing.

The high-speed projector projects binary images to the screen in time-division according to wavelength of the light.

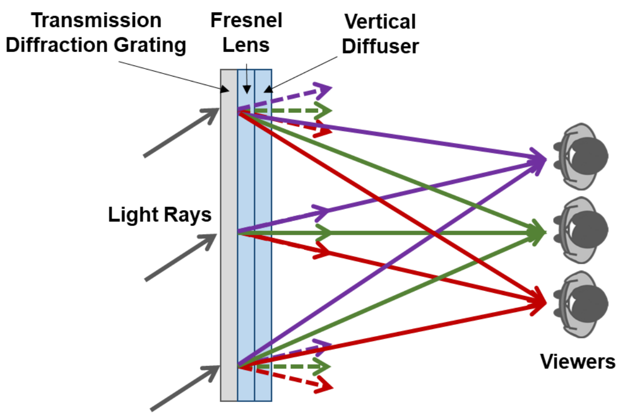

Figure 2. Scheme of spectroscopic screen

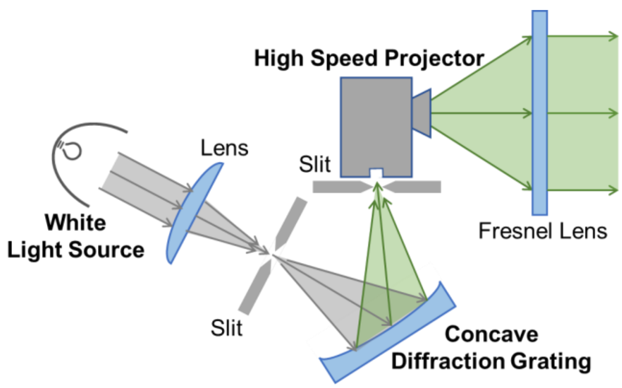

Figure 3. Scheme of wavelength modulation projector

Design Method

We designed the display to conduct computer simulation and experiment using prototype. Table 1 shows design values of the display. At first, we decided screen size, viewing distance, and wavelength bandwidth of display.

Design of Spectroscopic Screen

The screen shows 1st order light of transmission diffraction grating to viewers right in front of the screen. A relationship between incident angle α and diffraction angle β against the grating is expressed by an equation (1), where N is resolution of the grating, m is diffraction order, and λ is wavelength of light.

$$\sin\alpha - \sin\beta = Nm\lambda \tag{1}$$

Thus, the projector needs to project images from an angle against the screen. Furthermore, the higher resolution of transmission diffraction grating is, the larger viewing zone is; however, we have to note that incident angle of projection to the screen increases and aspect ratio of projection image changes. We decided the resolution of transmission diffraction grating to 1000 /mm based on value of actual one, so that incident angle of projection was 33.4 degrees and viewing zone was 182 mm. Also, focal length of Fresnel lens was set to 600 mm as same as viewing distance.

Design of Wavelength Modulation Projector

The high-speed projector projects 1st order light of the concave diffraction grating to the screen. Also the projector switch wavelength of projection image by swing motion of concave diffraction grating. A relationship between rotation angle of concave diffraction grating θ and wavelength of output light λ is expressed by an equation (2), where K is drift angle, N is resolution of the grating, and m is diffraction order.

$$2\sin\theta\cos K = Nm\lambda \tag{2}$$

We decided the resolution of concave diffraction grating to 600 mm based on value of actual one, so that required swing angle of the grating was 6.12 degrees. Width of output slit affects brightness of displayed image and crosstalk. When the width of output slit is large, the projector can project more light all at once and displayed image become bright; however, overlap of displayed images occurs because wavelength bandwidth of projection image become wide. Thus, it is needed to decide width of output slit considering balance of both. We decided width of output slit to 0.5 mm, and so bandwidth of a projection image was 15 nm. Also, frame rate of projection was set to 21600 fps so that number of viewing points would be 360.

Design of Scanning Wavelength Mechanism

The display uses lever-crank mechanism for swing concave diffraction grating to scan wavelength at high speed. As shown in Figure 4., in this mechanism, a lever (link c) swings when a crank (link a) rotates simply. A relationship between the rotation angle of crank θ and the swing angle of lever φ is expressed by equation (3), where a, b, c, d are each link lengths.

$$\varphi = \sin^{-1}\left(\frac{a\sin\theta}{\sqrt{a^2+b^2-2ab\cos\theta}}\right) + \cos^{-1}\left(\frac{a^2-b^2+c^2+d^2-2ab\sin\theta}{2c\sqrt{a^2+d^2-2ad\cos\theta}}\right) \tag{3}$$

Table 2 shows design value of link length ratio to obtain necessary swing angle.

Table 1 Design value of display

Item	Design value
Screen size (W × H)	300 × 188 mm
Viewing distance	600 mm
Viewing zone	182 mm
Wavelength bandwidth of display	400 - 700 nm
Refresh rate of display	60 Hz
Number of viewing points	360
Resolution of transmission diffraction grating	1000 /mm
Incident angle of projection	33.4 deg.
Focal length of Fresnel lens of screen	600 mm
Projection distance	500 mm
Resolution of concave diffraction grating	600 /mm
Swing angle of concave diffraction grating	6.12 deg.
Width of output slit	0.5 mm
Bandwidth of a projection image	15 nm
Frame rate of projection	21600 fps

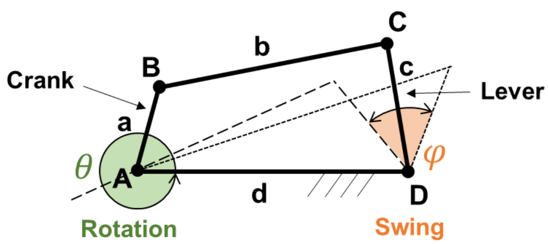

Figure 4. Lever-crank mechanism

Table 2 Ratio of link length

Link a	Link b	Link c	Link d
1.0	3.4	18.8	18.8

Computer Simulation

We conducted computer simulation based on the design value to confirm a principle of the display. We simulated optical characteristic of the spectroscopic screen when projector projects some light rays of 400, 550, 700 nm as shown in Figure 5. It is found that light rays passed through the screen converge each viewing points depending on its wavelength. Also, we simulated displayed image of the screen by using ray tracing software POV-Ray as shown in Figure 6. It is found that the screen shows images with appropriate horizontal parallax. From these results, we confirmed that the proposed display can show 3D image of which color depends on viewing points.

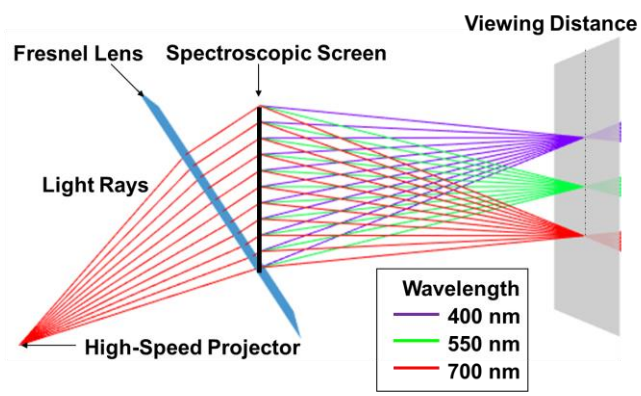

Figure 5. Optical characteristic of the spectroscopic screen

Conclusion

In this paper, we proposed a new large screen 3D display which enables multiple viewers to see simultaneously without special glasses using wavelength division multiplexing. We conducted computer simulation based on the design values and confirmed that the proposed display can show 3D image of which different color depending on viewing points. The future work is to made a prototype of the proposed display and conduct experiments to verified the principle.

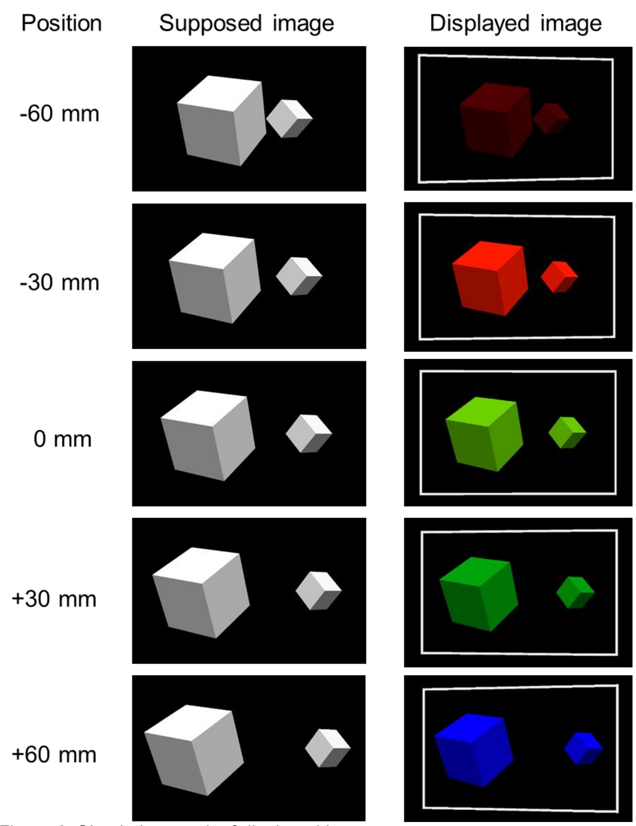

Figure 6. Simulation result of displayed image

Acknowledgement

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Author Biography

Masaki Yamauchi was born in Iwate prefecture, Japan, in 1996. He received the B.E. degree in Department of Electrical, Electronics and Information Engineering from Nagaoka University of Technology, Niigata Japan, in 2018. He is now a master course student of Nagaoka University of Technology. His research has focused on the development of 3D display.