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Projection type light field display using undulating screen

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Abstract

We propose a new 3D display using single high-speed projector and undulating screen which is thin and flexible. Traveling waves are generated on the screen. The proposed display enables to display 3D image by scanning light beam from the projector with the traveling waves. The principal aim of this proposal is producing a large screen 3D display which enables multiple viewers to see 3D image without special glasses. In previous studies, large screen 3D displays using many projectors are proposed. However, as number of projectors are large, it is difficult to install and adjust them. On the other hand, a large screen 3D display using single high-speed projector exploiting time-division multiplexing is proposed. To scan the light beam from the projector, the screen of the display swings around vertical axis direction. Moreover, the screen is split vertically for reduce moment of inertia. Each strip of screens need power transmission mechanisms. Many mechanisms make apparatus large scale and complex. Our new system makes apparatus simple because all over the screen is controlled with single driving method. To confirm the principle of the proposed method, we conducted a computer simulation and confirmed that proposed system displays 3D image which has appropriate parallax.

Introduction

Applications using stereoscopic images have begun using for various situations. Various types of three-dimensional(3D) display have been developing according to applications. See-through 3D display is one of them. There are various types see-through 3D displays such as head-mounted display type, using holographic elements and so on [1–4]. It is possible to display 3D image superimposed on real-world environment by using see-through 3D display. The 3D display is widely used including work support and entertainment and so on. One of them is an exhibition field such as showcase and shop window. By replacing the area of the window with 3D display, displaying additional information of exhibited object, emphasizing exhibited object, it is expected to high propaganda effect. In a limited exhibition space, even if a real object that cannot be placed actually, 3D image can be displayed.

In exhibition field, it is supposed that 3D display is watched by multiple viewers at the same time. Therefore, it is required that large screen 3D display enable to multiple viewers to see 3D image with naked-eye. In previous studies, projection type 3D display [5] [6] are proposed. Projection type 3D display is suitable for large screen display, although screen size of these displays are not large yet. We have proposed a 3D display using single high speed projector and swinging screens [7]. The features of this display are that it has large screen, several people can observe with the naked-eye at the same time, the screen has transparency and the projection unit is small scale. However, because the screen is split, it is necessary to transmit power to all strip screen for swinging. Thereby, apparatus of the screen is large scale and complex.

In this study, we propose a new 3D display exploiting time-division multiplexing which is composed of single high speed projector and undulating screen. The traveling wave is generated on the screen. To generate the traveling wave on the screen, oscillating sources are placed at both ends of the screen. Because the oscillating sources are consolidated on the both ends of the screen, apparatus of the screen is small scale and simple. We confirmed the principle of the proposed method by computer simulation.

Proposed method

Schematic image of the proposed display is shown in Figure 1. The proposed display consists of single high-speed projector and thin and flexible screen. The rays from the projector are reflected at the screen. The direction of the reflected rays are varied by undulating of the screen. It is possible to display 3D image by changing projection images corresponding to reflection direction at high-speed.

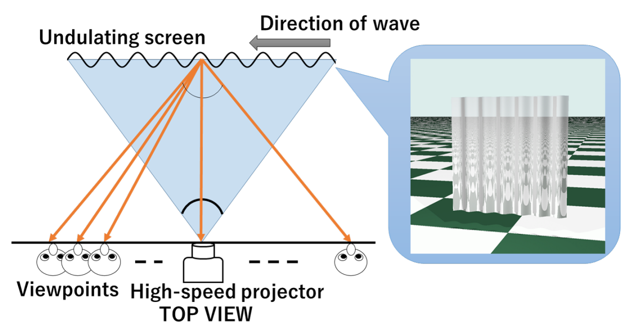

Figure 1. *Schematic image of the proposed display.*

Undulating screen

Necessity for traveling wave

This section describes about necessity for traveling wave. When the screen is oscillated, certain wave is generated on the screen. The wave is considered as "Traveling wave" or "Standing wave". The equation of sine traveling wave and sine standing wave are given as equation(1) and equation(2).

$$f_{tr}(x,t) = A\sin 2\pi\left(\frac{x}{\lambda} - ft\right) \quad (1)$$

$$f_{st}(x,t) = 2A\sin 2\pi\left(\frac{x}{\lambda}\right)\cos 2\pi(ft) \quad (2)$$

Now, differentiate equation(1) and equation(2) with respect to x gives equation(3) and equation(4). Equation(3) and equation(4) express slope of the wave.

$$f'_{tr}(x,t) = \frac{2\pi A}{\lambda}\cos 2\pi\left(\frac{x}{\lambda} - ft\right) \quad (3)$$

$$f'_{st}(x,t) = \frac{4\pi A}{\lambda}\cos 2\pi\left(\frac{x}{\lambda}\right)\cos 2\pi(ft) \quad (4)$$

The screen of the proposed display is required to vary the normal direction with time. In other words, the slope of the generated wave on the screen need to vary with time. Moreover, to display 3D image at every position of the screen, it is necessary to vary the slope at every position uniformly. In the case of traveling wave, as can be seen from equation(3), the slope is uniformly varied at every position with time. However, in the case of standing wave, as can be seen from equation(4), coefficient of "$\cos 2\pi(ft)$" including time variant t depends on position variant x. Therefore, the slope is not varied uniformaly. If position variant x satisfies following equation $x = n\lambda/4 \quad (n = 1,2,3...)$, the slope is always "0". At the position $x = n\lambda/4$, ray from the projector is not scanned. Hence, in proposed method, we exploit traveling wave for scanning.

Generation of traveling wave

To generate traveling wave on the screen, oscillating sources are placed at both ends of the screen. When oscillation occurs at one end, the oscillation becomes traveling wave and propagates on the screen toward the other end. At this time, reflected wave is generated according to the boundary condition of the end point. When the generated reflected wave interferes with the traveling wave, standing wave is generated on the screen. If the reflected wave can be eliminated, there is only traveling wave on the screen. Let us consider what the boundary condition for eliminating the reflected wave is. Supposing the screen has infinite length, reflected wave is never generated. Namely, if it is possible to reproduce the behavior occurring on infinite length screen at the end point of finite length screen, reflected wave is not generated. The boundary condition is the behavior that must be reproduced. From the above, at one end of the screen, there is an oscillating source for generating wave. At the other end of the screen, there is also an oscillating source for reproducing the behavior of infinite length screen.

Traveling wave form

The traveling wave is generated in the horizontal direction on the screen standing vertically. Thereby, rays from the projector are scanned in horizontal direction. The scanning angle range is determined by the form of generated traveling wave, and the scanning frequency is determined by the frequency of the wave. This section describes about procedure for designing the scanning angle range and scanning frequency. In the proposed display, the traveling wave is in the form of sine wave.

First, the procedure for designing the scanning frequency is described. The scanning frequency is designed based on the refresh rate of the display. While the traveling wave propagates for one period, the ray from the projector is scanned from end to end of scanning angle range. Therefore, scanning frequency is equal to traveling wave frequency, the frequency is determined so that equals refresh rate of the display. The refresh rate of the display has to have high frequency in order not to be felt flicker by human eyes.

Next, the procedure for designing the scanning angle range is described. Figure 2 shows top view of the screen standing vertically. Here, the wave propagation direction is the X axis, the direction in which the screen stands is the Y axis, and the direction in which the wave oscillates is the Z axis.

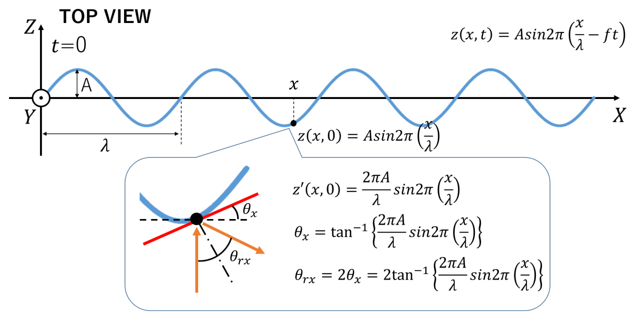

Figure 2. *When t=0, Form of traveling wave -Calculation process of reflection angle-.*

The following three equations are used to design the scanning angle range.

$$v = \sqrt{\frac{T}{\sigma}} \quad (5)$$

$$v = f \times \lambda \quad (6)$$

$$z(x,t) = A\sin 2\pi\left(\frac{x}{\lambda} - ft\right) \quad (7)$$

Equation(5) is an equation to determine the propagation velocity of a wave from tension "T" and line density "σ". Equation(6) is relational equation indicating a relation between the frequency "f", the wavelength "λ" and the propagation velocity "v". Equation(7) is an equation to obtain a Z axis coordinate of the screen when the sine traveling wave is generated on the screen. Here, the "A" is the wave amplitude.

The scanning angle at a certain point can be obtained from the slope of the screen at the point. The equation expressing the slope of the screen is given as equation(8).

$$z'(x,t) = \frac{2\pi A}{\lambda}\cos 2\pi\left(\frac{x}{\lambda} - ft\right) \quad (8)$$

The reflection angle range is twice the slope angle range, the scanning angle range is equal to the reflection angle range. The scanning angle range is given as equation(10).

$$\theta_s = 2\tan^{-1}\max_x\left\{\frac{2\pi A}{\lambda}\cos 2\pi\left(\frac{x}{\lambda} - ft\right)\right\} \quad (9)$$

$$= 2\tan^{-1}\left\{\frac{2\pi A}{\lambda}\right\} \quad (10)$$

The scannning angle range can be obtained from amplitude "A" and wavelength "λ" as can be seen from equation(10).

Now, the amplitude and wavelength also have relationship with the angular resolution of reflection angle separately from the scanning angle range. Figure 3 shows the relationship between amplitude, wavelength, and angular resolution.

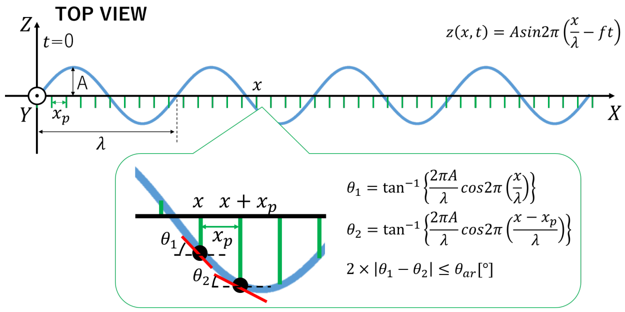

Figure 3. *When t=0, Form of traveling wave -Calculation process of angular resolution-.*

A pixel width of projection image on the screen is determined from the resolution of the projector and the projection distance. In a pixel width, the slope angle of the screen is varied continuously. However, since it is impossible to separate the intensity of the ray from the projector in a pixel width, the rays with the same intensity are reflected differnt angles slightly. Particularly in the mountains and valleys of waves, the angular displacement of the slope of the screen is large, so that the range of the reflection angle is large. The range of the reflection angle at the position where the angular displacement of the slope of the screen is the maximum is the angular resolution of the display. It is required that the range of reflection angle is less than the desired value. The equation of angular resolution "θ_{ar}" is given as equation(12).

$$\theta_{ar} \geq \max_x \left\{ 2\tan^{-1}\left\{\frac{2\pi A}{\lambda}\cos 2\pi\left(\frac{x - xp}{\lambda} - ft\right)\right\} - 2\tan^{-1}\left\{\frac{2\pi A}{\lambda}\cos 2\pi\left(\frac{x}{\lambda} - ft\right)\right\}\right\} \tag{11}$$

$$\geq 2\tan^{-1}\left\{\frac{2kA\sin\frac{kx_p}{2}}{1 - k^2A^2\sin^2\frac{kx_p}{2}}\right\} \quad (* k = \frac{2\pi}{\lambda}) \tag{12}$$

Here, the "x_p" is a pixel width of projection image on the screen. When the desired scanning angle and angular resolution are set and the pixel width on the screen is determined based on the resolution of the projector, the minimum wavelength and amplitude capable of being set are obtained from the equations (10) ,(12).

Finally, let us consider about propagation velocity of a wave. The desired value of wave propagation velocity is calculated using the equation (6). The frequency "f" is designed based on the refresh rate of the display, and the minimum value of the wavelength "λ" is also calculated. The product of frequency and wavelength is the desired value of the propagation velocity. The tension "T" and line density "σ" are adjusted so that the calculated value using the equation(5) is equal to the desired value. However, there are some cases that the calculated value using the equation(5) is not equal to the desired value because there are some restrictions of selection of a material. In that cases, the design value of the propagation velocity is redesigned by changing the wavelength under the restrictions of the equation(12).

The above is the design procedure for scanning angle range and scanning frequency.

Screen material

In horizontal direction, the screen reflects rays from the projector specularly to display different image for different viewpoints. In vertical direction, the screen reflects diffusely so that 3D image can be observed independently from viewing zone because we want to observe 3D image on the screen independent of viewing position in vertical direction. Moreover, the screen is required see-through property to superimpose on real objects behind the screen. In addition, the screen is required to be thin and flexible. As an example of a screen which is satisfied the above, there is a transparent and flexible material such as polypropylene which is deposited metal thinly like a half-mirror.

Projection image

Projection images are created by ray tracing method based on projector and screen position and traveling wave form information. The screen shape is changed with time due to the propagation of the traveling wave. The projection image is changed according to the varying the screen shape. The maximum number of projection images "N" is given as equation(13).

$$N = \frac{R_p}{f} \tag{13}$$

Here, the "R_p" is refresh rate of the projector, "f" is the frequency of the traveling wave.

Figure 4 shows the procedure of creating projection images. First, the models of projector and the screen are placed. Second, X axis coordinates of each pixel of the projection images on the screen are calculated from the resolution of the projection image. Since the screen of the proposed display reflects ray from the projector diffusely in vertical direction, it is not necessary to calculate about Y axis coordinate. Third, the center rays of each pixel are traced to the points which is "VD" distant from the screen. Fourth, parallax images when viewing the 3D object from the points where traced rays reach are prepared. Finally, the pixel values of rows of the parallax images corresponding to the x-axis coordinate of the pixel which did ray-tracing are extracted, the extracted values are recorded to the same pixels of projection image.

Computer simulations

To confirm the principle of the proposed method, we conducted a computer simulation using ray tracing tool of "POV-Ray".

Simulation condition

Simulation parameters are based on Table1. We simulate the image which is displayed on the screen while the traveling wave is propagated in one period. Number of simulation times are 1200 times per one period. The simulated result is integrated image which is combined simulating images of 1200 times.

Table 1 Parameters of computer simulation

Screen size	900 * 900 [mm]
Amplitude of the traveling wave	11.359 [mm]
Wavelength of the traveling wave	142.74 [mm]
Scanning angle range	60 [degrees]
Viewing distance	2160.39 [mm]
Angle of view of projector	23.53 [degrees]
Projection distance	2160.39 [mm]
Projection image size	900 * 900 [pixel]
Number of projection images in a period	1200
Projection object	dice

Simulation results

Figure 5 show simulated results and parallax image which is observed from three viewpoint. From the simulated results, we confirmed that our proposed system displays 3D image which has appropriate parallax.

Conclusion

In this study, we proposed a new 3D display exploiting time-division multiplexing which is composed of single high speed projector and undulating screen. Our new system makes apparatus of display small scale and simple. To confirm the principle of the proposed method, we conducted a computer simulation. From the simulated results, we confirmed that our proposed system displays 3D image which has appropriate parallax.

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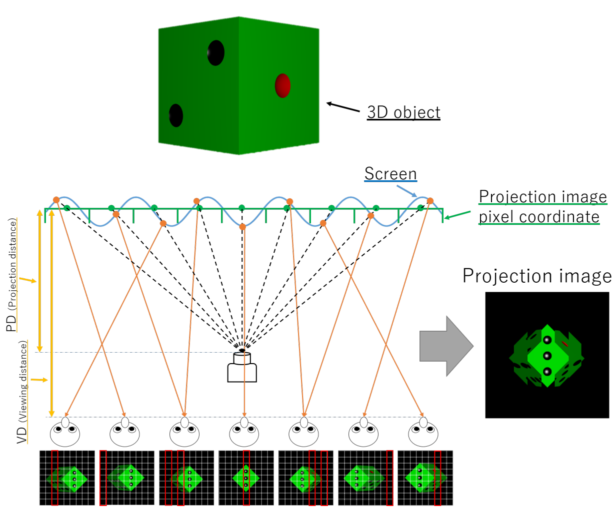

Figure 4. *Projection image creating procedure*

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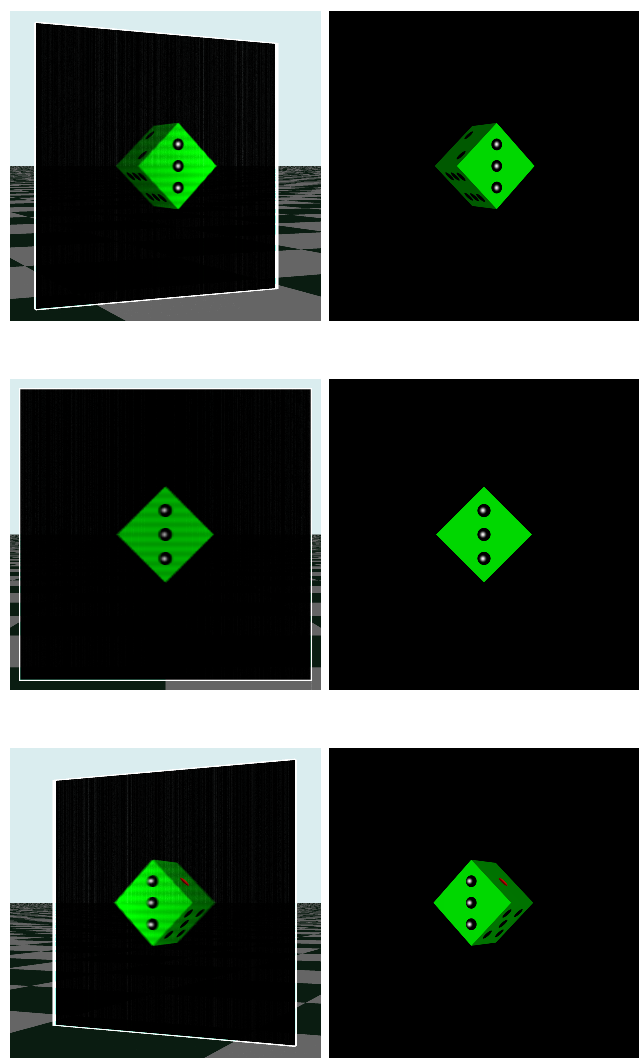

(a)Simulated image (b)Parallax image

Figure 5. *Simulated results*

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Author Biography

Masahiro Kajimoto was born in Nara prefecture, Japan, in 1994. Masahiro Kajimoto received the B.E. degree in Department of Electrical, Electronics and Information Engineering from Nagaoka University of Technology, Niigata Japan, in 2016. He is now a master course student of Nagaoka University of Technology. His research interest includes stereoscopic image technology.