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Study of eye tracking type super multi-view display using time division multiplexing

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Abstract

In recent year, the Head-up display is studied actively. Among them, 3D HUD attracts rising attention. In HUD application, it is assumed that stereoscopic image is displayed at far distance. Super Multi-View display provides a smooth parallax. Even if 3D image is at far distance, it be able to display 3D image which has appropriate depth. In previous studies, high resolution required for SMV. However, there are restrictions to increase the resolution. Therefore, we propose a novel SMV display using time division multiplexing and eye tracking techniques. Our new system is not required high resolution display. The proposed display consists of DMD and light source array. The ray from the light source array is reflected at DMD, and form an image at the vicinity of the pupil. The position forming an image depends on light source position. The image which is display on the DMD is changed corresponding to the focal point. To confirm the principle of the proposed method, we experiment about creating a viewing zone only in the vicinity of the pupil. From the result, we confirmed 8 viewpoints in the horizontal direction at 18.8 mm viewing zone.

Introduction

In recent years, research on HUD has been actively conducted, and research on super multi-view type HUD [1] enabling natural stereoscopic viewing is conducted. Super multi-view display has a feature that viewpoint pitch is less than the pupil diameter. It has been reported that discontinuity of motion parallax and accommodation-vergence conflict can be resolved. In the current super multi-view display, it needs display device with huge quantities of pixels (resolution in one viewpoint × number of viewpoints) because high density of parallax images and large field of view are regenerated at the same time. Therefore, it is difficult to increase the number of viewpoints and improve image quality in current system. In order to overcome this problem, methods using time division multiplexing [2] have been studied. Each viewpoint is discretely reproduced in the time direction by directional control of rays and switching of projected image. At this time, the whole pixels of the display device are used only for generate of one viewpoint. Therefore, this super multi-view display don't required high resolution device. However, since the switching speed of the projected image is the limit of the number of viewpoints, it is difficult to create more viewpoints. Therefore, this study focused on the fact that the ray entering the pupil of the observer is a part of the ray of the entire viewing zone. We propose a super multi-view display HUD which reduces the number of viewpoints to be reproduced by tracking the pupil and irradiating only the vicinity of the pupil. In this report, we discussed a method to create a viewing zone only in the vicinity of the pupil and confirm the effectiveness as a HUD by confirming fine disparity in a long distance image.

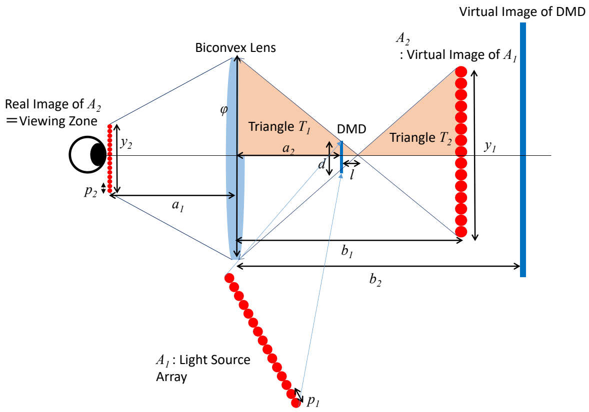

Figure 1. Schematic image of the optical system

Method

The configuration of the time division super multi-view HUD that limits the viewing zone only in the vicinity of the pupil will be illustrated. It is configured by light source array, Digital Micromirror Device (DMD), and biconvex lens. Fig. 1 shows schematic image of the optical system. Notice the lens and DMD. By making the position of the DMD closer than the focal length, that is, $a_2 < f$, the virtual image of the DMD is formed at the distance b_2. The image displayed on the DMD is enlarged display with this virtual image. Notice the light source array and DMD. The virtual image A_2 of light source array reflected by DMD is formed at the position of the distance b_1. Notice the lens and light source array. The real image A_3 of the light source array is formed as an array of viewpoints by the convex lens, by the virtual image A_2 of the light source reflected by the DMD.

Next, viewpoint formation by time division multiplexing will be illustrated. The LEDs lined up vertically and horizontally turn on one by one. As a result, the position of the real image of one LED on the viewing zone is switched. An image of the DMD is observed only when an eye is placed at the position of the real image of one LED. In addition, a parallax image corresponding to the position of the real image of the LED is displayed on the DMD. By switching this lighting position and switching the image of the DMD at high speed, it is possible to observe the parallax images corresponding to each position from the each viewpoints. At this time, since the whole pixel of the DMD is used to generate one viewpoint, super multi-view display can be realized without requiring a high resolution device. Further, the viewpoint position is switched by controlling the lighting position of the LED, and the projection image is switched by the DMD. Therefore, time division multiplexing without using mechanical structure is realized.

The relationship of parameters required for design will be illustrated. In the light source array, LEDs are arrayed vertically and horizontally. The viewpoint pitch p_2 is determined by the LED pitch p_1 and magnification of the real image of LED array.

$$p_2 = p_1 \frac{b_1}{a_1} \tag{1}$$

At this time, a_1 and b_1 are determined from the focal length f of the lens.

$$\frac{1}{a_1} + \frac{1}{b_1} = \frac{1}{f} \tag{2}$$

Next, viewing zone y_2 is given as equation(3).

$$y_2 = y_1 \frac{b_1}{a_1} \tag{3}$$

As can be seen from equation, viewing zone is depended on the size of the light source array y_1. The range of the virtual image A_2 of the light source is set so that the light from the entire DMD is incident on the entire lens. At that time, Triangle T1, Triangle T2 are created as shown in Figure 1. Since Triangle T1 and Triangle T2 have a similar relationship, the maximum size y_1 of the light source array can be obtained from the equations (4) and (5). $y_1$depends on the lens diameter φ , the size of the DLP d, and the distance between the DLP and the lens.

$$y_1 = \frac{\varphi(b_1 - a_2 - l)}{a_2 + l} \tag{4}$$

$$l = \frac{d}{(\varphi - d)} \tag{5}$$

In this study, since the viewing zone is formed only in the vicinity of the pupil, the viewing zone is required about y 2 $>$ 10 mm. Also, the view angle θ of the virtual image of the observed DMD is shown in the equation (6).

$$\theta = 2\tan^{-1}\left(\frac{b_2 d}{2a_2(a_1 + b_2)}\right) \tag{6}$$

Next, we will discuss the placement restriction of DMD used in this study and light source. The DMD used in this study is DLP 7000 which is manufactured by TEXAS INSTRUMENTS. The DMD is an array of micromirrors, and the each mirrors are tilted so that the reflection direction of light is controlled and an image is projected. In the DLP 7000, since the diagonal line of each micromirror is tilted about the axis, the position of the light source needs to be shifted by 45 ° as shown in Figure 2 (a). Also, each micromirror of this DMD tilts ± 12 °. In order to generate an image of the light source array formed by the DMD on the optical axis of the lens, the light source array must be tilted by 12 ° as shown in Figure 2 (b).

Experimental Condition

Design the actual optical system based on the relationship of parameters described in the method. In this study, we designed the optical system to observe the DLP image 10m ahead and to create 8 viewpoints in the viewing zone of 10mm in the horizontal. Also, by placing an acrylic plate between the lens and the viewpoint, the image and the real object are superimposed and displayed. Specific parameters are shown in Table 1. Fig 3 shows the optical system actually assembled. Table 2 shows the specifications of the DMD used in the study. A projection experiment was conducted under these conditions.

Table 1: Parameters of the optical system

Focal length of lens : f	200 mm
Lens diameter : φ	100 mm
Lens – viewpoint distance : a_1	300 mm
Lens – Light source distance : b_1	600 mm
Lens – DMD distance : a_2	195.95 mm
Lens – DMD virtual image distance : b_2	9700 mm
Viewpoint – DMD virtual image distance : $a_1 + b_2$	10000 mm
Number of LEDs	8×1
LED pitch : p_1	2.5 mm
Viewpoint pitch : p_2	1.25 mm
Viewing zone : y_2	10 mm×1.25 mm
Size of DMD : d	14.008 mm× 10.506 mm
Angle of field : θ	3.971° × 2.979°

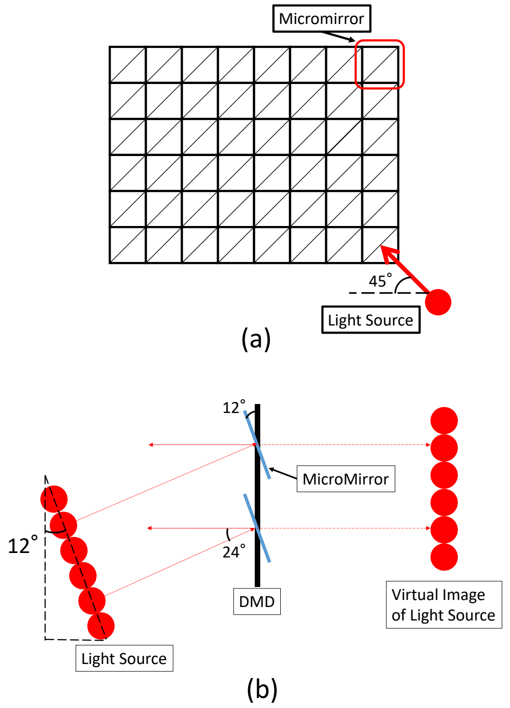

Figure 2. Placement restriction of DMD and light source

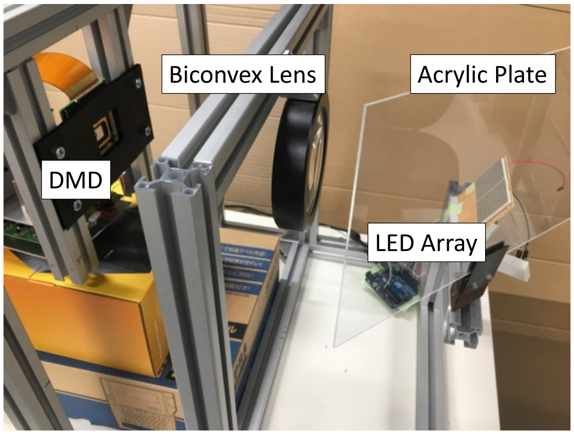

Figure 3. The installed optical system

Table 2: Parameters of the Digital Micromirror Device

Manufacturer	TEXAS INSTRUMENTS
Model Number	DLP7000
Resolution	1024×768
Micromirror pixel pitch	13.68 μm
Size of DMD	14.008 mm × 10.506 mm
Micromirror tilt angle	±12°

Experimental Results

First, we conducted an experiment to check whether the projected image was created at the set position. Fig. 4 shows the image taken. The camera was moved in the horizontal direction so that parallax images for the eight viewpoints from the initial position were taken respectively. Fig 5 shows a graph of the distance of the difference from the camera position before one viewpoint and the moving distance of the projected object on the photographed image. We also made similar measurements on real objects placed at assumed distance. From these results, the position of the created image plane is obtained by the principle of distance measurement of the stereo camera from the parallax image taken from each viewpoint and the distance of the camera moved. Camera and lens parameters for calculation are the pixel size of the camera and the focal length of the lens. Table 3 shows the parameters of the camera and lens used for taking pictures. Assuming that distance from the image plane to the lens of camera is L, the focal length is f, the distance between two points of the camera is D, the distance between two points of the object in photographed image is a, distance L is obtained by equation(7).

$$L = \frac{DF}{ap} \tag{7}$$

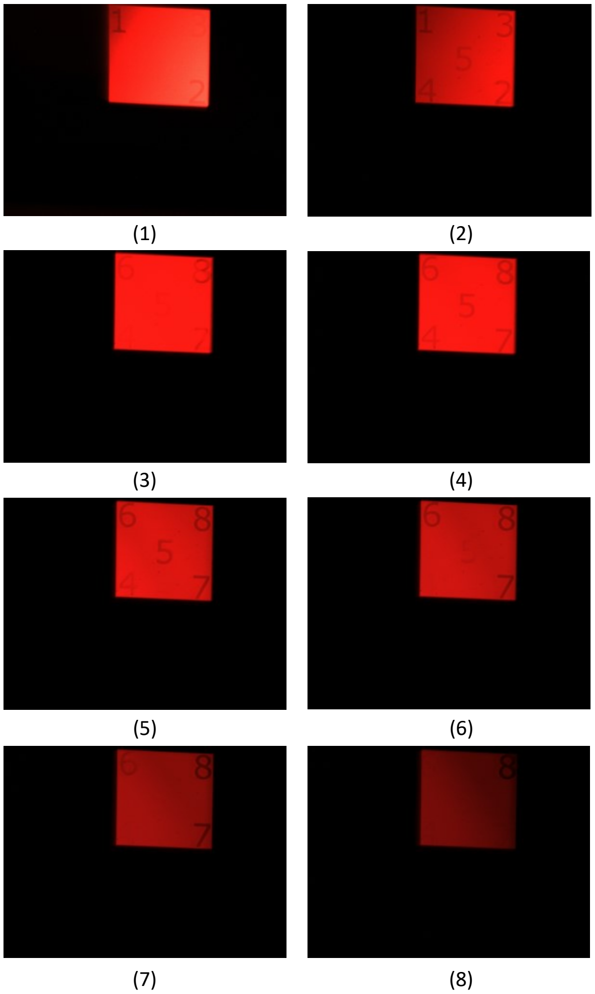
(1) (2) (3) (4) (5) (6) (7) (8)

Figure 4. Parallax images of the eight viewpoints photography

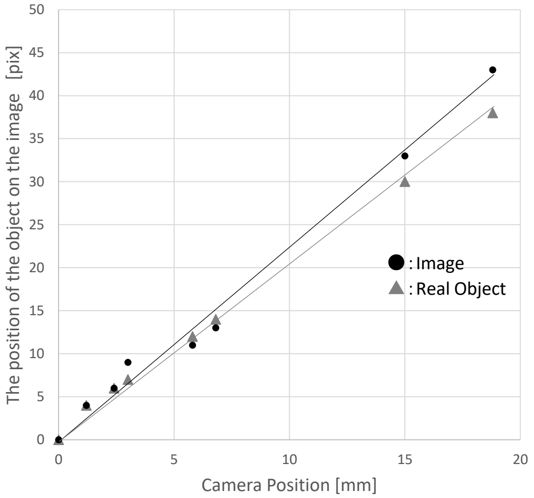

Figure 5. Comparison of created image plane with real object at assumed position

In this example, $D = 18.8$mm, because the two points taken are the position of the 1 and 8 images. The moving distance of the object on the photographed image at this time was 43 pix in the created image. Therefore, $L = 8.7$m

Next, in order to enable HUD, superimposed with real object. As shown in Fig. 3, by placing an acrylic plate assuming a windshield between the viewpoint and the lens, superimposed display is enabled. The result is shown in Figure 6. The real object was installed 8.7 m ahead from the viewpoint, and the projected image and the real object were simultaneously observed.

Consideration

First, from the graph of Fig. 5, the created viewing area was 18.8 mm, wider than the assumed 10 mm. It is considered that the reason is the distance between the lens and the light source was not correct. It is necessary to consider a method of accurately setting the light source in units of 1 mm. Also, it is a problem that the viewpoint intervals are not evenly spaced. It is conceivable that the light source array is installed inclined in the depth direction and image blur due to lens distortion is caused. Stable installation of the light source array and choice of lens are also issues.

Next, the position of the measured image plane is considered. When creating an image plane to the measured 8.7 m, the distance between the lens and the DMD is 195.373 mm. When creating an image plane to the assumed 10 m ahead, the distance between the lens and the DMD is 195.959 mm, which is only 0.586 mm difference. Currently, it is thought that it is very difficult to adjust the unit of 0.1 mm in the aluminum frame used for installation, so a change to a more finely adjustable installation method can be considered as one improvement method. Moreover, by using a lens with a longer focal length, improvement can be contributed by giving a margin to the distance between the lens and the DMD.

Conclusion

In this study, we created a super multi-view HUD by time-division multiplexing, limiting the viewing zone creation only in the vicinity of the pupil. And we evaluated the image plane distance. As a result, eight viewpoints were created in the viewing zone of 18.8 mm in the horizontal, and the image plane was created 8.7 m ahead from the viewing zone.

Acknowledgment

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References

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Table 3: Parameters of Camera and Lens

Manufacturer of Camera	Point Grey Research
Model Number of Camera	Flea3 FL3-U3-32S2C
Pixel size : p	2.5 μm
Manufacturer of Lens	SPACECOM
Model Number of Lens	JHF50M
Focal length : f	50 mm
Angle of field : θ	10°×7.5°

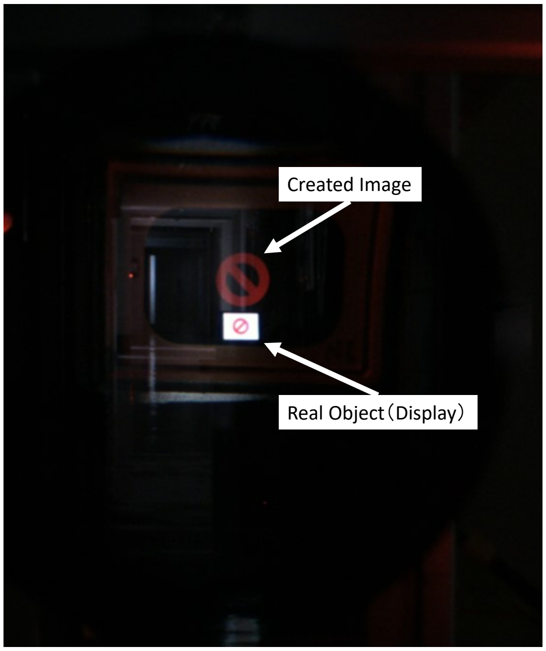

Figure 6. Superimposition with real objects

Author Biography

Yuta Takahashi was born in Tochigi prefecture, Japan, in 1994. Yuta Takahashi received the B.E. degree in Department of Electronic Control Engineering from National Institute of Technology, Oyama College, Tochigi Japan, in 2016. He is now a master course student of Nagaoka University of Technology. His research interest includes stereoscopic image technology.