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Transparent type virtual image display using small mirror array

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Abstract

There is a demand to display image on a transparent medium. If we can show image superimposed on a window, it can attract interest of people. However, a current achieved transparent displays show images only on the display surface, hence it is difficult to show image superimposed on an object that exists behind the screen. Thus, it doesn't understand intuitively. On the other hand, a display which can be perceived the image behind the screen should be placed inclined. Therefore, it is difficult to apply to advertising and exhibition. The purpose of this study is to generate transparent display to show image superimposed on near an object that exists behind the screen. We propose a display which shows image not on display surface but at a different image of depth. In this system, to show the image at behind the screen, display device is reflected on the transparent screen which incorporates a half mirror array. In this study, we use the mirror array as screen in order to locate the display device at an appropriate place. We optimize the surface of display device and angle of all mirrors so as to minimize the virtual image distortion. To confirm the practicality of the proposed method, we conducted a simulation. From the result, we confirmed the virtual image was able to display designated position.

Introduction

Applications using an imaging technology such as Virtual Reality (VR) and Augmented Reality (AR) have been attracted attention. These technologies have spread widely as product and application software. In AR application, a screen is required see-through property because it displays an information (digital image) superimposed on real-world environment. One of typical example of display for AR application is “HoloLens” which is manufactured by Microsoft company. This display is Head Mounted Display (HMD). Not only HMD but also naked-eye type see-through AR display has been studied. Naked-eye type AR display suits to display information for multiple viewers. If a naked-eye type see-through large screen AR display is realized, it is useful for advertisement and exhibition application. Here, we think such display to be installed on shop window, it needs following two characteristics. The first, an observed image is perceived near the real object behind the screen because of intuitive understanding. The second, the screen can be placed vertical on the ground because almost all shop windows are vertical on a ground.

Several transparent displays are commercialized including a general transparent display typified by "Smart Display Window" which is manufactured by DNP company. The general transparent display has wide viewing angle and large screen because it is expected to apply for show room and exhibition. However, the image cannot be perceived near the real object when it used in the shop window because it is perceived the image only the screen surface.

On the other hand, "Z-Cube19" is system manufactured by KAWASAKI KOGYO CO., LTD which the observed image can be perceived behind a screen. However, it is difficult to apply for advertising and exhibition because the screen is not vertical on a ground. There is no conventional display which satisfy all characteristics mentioned above.

In this paper, we propose the naked eye type transparent display which is placed vertical on the ground and the image is perceived behind the screen. The proposed display consists of a display device and a half mirror array (screen) which is implemented inside of transparent medium. The screen has transparency in order to display the image superimposed on a real object. In this paper, we report the simulation result which confirmed the principal of the display.

Proposed method

(1) Previous verification

In this study, the virtual image of the display device is generating by reflecting on the screen so that observed image is perceived at far from screen. Concretely speaking, we use the virtual image which is made by mirror. Figure 1 shows the situation which use a plane mirror. In the case of plane mirror, object and virtual image are located on symmetrical. Thus, when the images display in front of the viewer, the display device prevents the observation and when the virtual image displays at too far from screen, it is difficult to place the object symmetrical location. Therefore, it is difficult to implement using plane mirror.

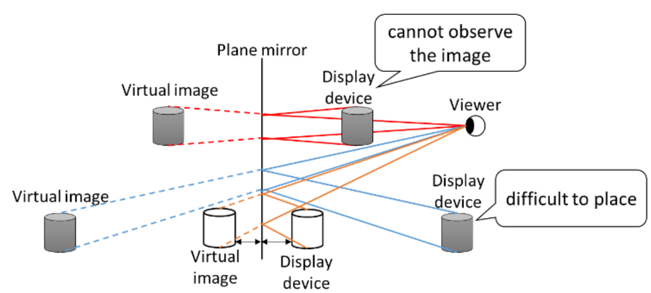


Figure 1 Situation of using plane mirror

(2) Overall view of proposed system

Schematic view of proposed display is shown in Figure 2. In this system, to show the image at behind the screen, display device is reflected on the transparent screen which incorporates a mirror array. Using a mirror array as a screen instead of planar mirror enables to locate the display device at an appropriate place. We optimize the angle of all mirrors so as to minimize the virtual image distortion. To secure the transparency, we use half mirror array.

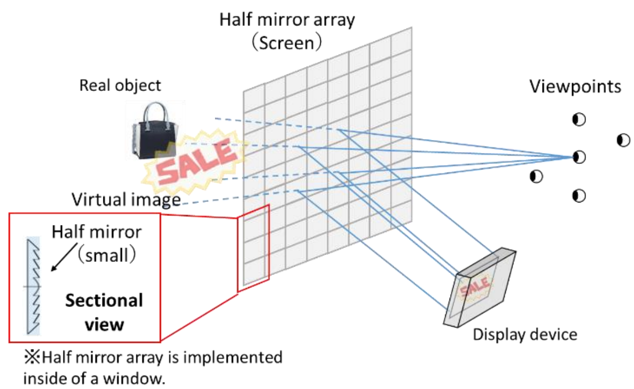


Figure 2 Schematic view of proposed display

(3) Problem

We consider about the problem to use half mirror array. It is predicted to occur the observed image distortion and incorrect motion parallax because mirror angle is different by location. Figure 3 shows an example of simple design method of mirror array. The angle of each mirror is designed so that correct image can be observed from referenced viewpoint. If viewer observe the image from other place, the pixel same as original cannot be referenced because mirror angle is calculated to base on referenced viewpoint. Therefore, distortion is occurred shows Figure 2. From the point view to apply for advertising and exhibition, viewers should be able to observe the similar image from anywhere. We should decide the mirror angle which can reference the pixel of close to pixel that observe by referenced viewpoint from anywhere. In addition, parameters of display device which determine location and surface shape should be decided. We can obtain that observe an image which has small distortion and provide the correct motion parallax. For that reason, we consider the design method how to design each parameter.

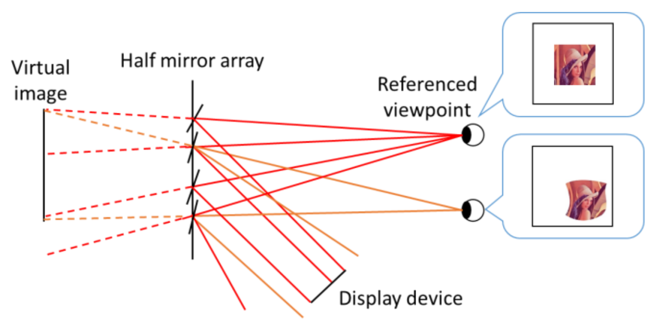


Figure 3 problem of using small half mirror array

Optimization

We optimize the parameters other than parameters of virtual image that using the parameter concerned with virtual image. The optimization procedure consists of inside loop which optimize the mirror angle and outside loop which optimize the shape of the surface of display device. Figure 4 shows a flow chart of this optimization.

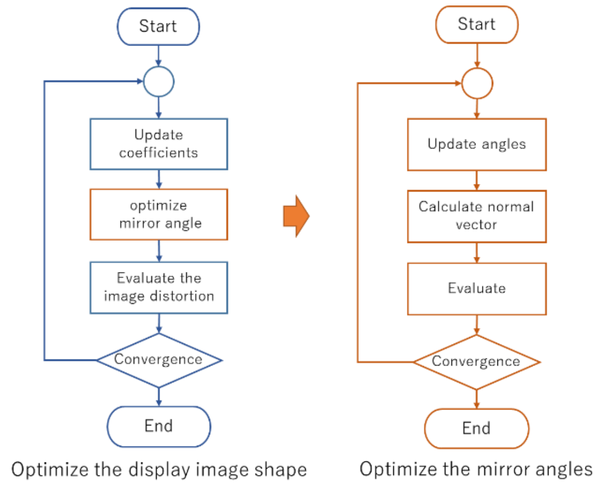


Figure 4 Flow chart

(1) Angle optimization

We use equation 1 as objective function in order to optimize a normal vector distribution of mirror array. The normal vector is designed by minimizing the function.

$$f(normalVec) = \sum_{k=0}^{NUM} \left|\overrightarrow{Q_k} - \overrightarrow{refP_k}\right|^2 \qquad (1)$$

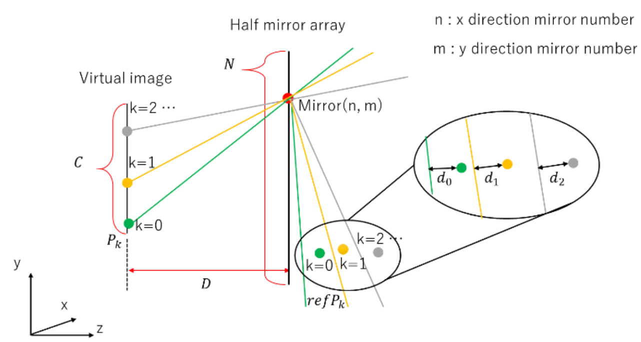


Figure 5 Optimize the mirror angles

In Figure 5, we consider selected pixels in the virtual image and a one mirror in the mirror array. First, we defined pixels of display image correspond to each pixel of the virtual image. A ray through the mirror to a pixel reflect on mirror. This reflected ray hereinafter referred to $\overrightarrow{ref\_d_k}$. An intersection points between a plane which includes the pixel of display image and has normal vector called $\overrightarrow{ref\_d_k}$ and reflected ray $\overrightarrow{ref\_d_k}$ is defined. It hereinafter referred to Q_k.

The intersection points are calculated to all selected pixel in the virtual image and evaluation value is calculated by using equation 1. By doing this, we get the distribution of normal vector which low variation of rays that approach to the pixels.

(2) Optimize the surface of display device

We use an equation 2 for objective function in order to optimize surface of display device. This function represents the distortion of virtual image which observed from each viewpoint. The surface is designed for minimizing the function.

$$f(ImageShape) = \sum_{v=1}^{E_{NUM}} \sum_{p=0}^{P_{NUM}} \left|Q_{p,v} - Q_{p,0}\right|^2 \tag{2}$$

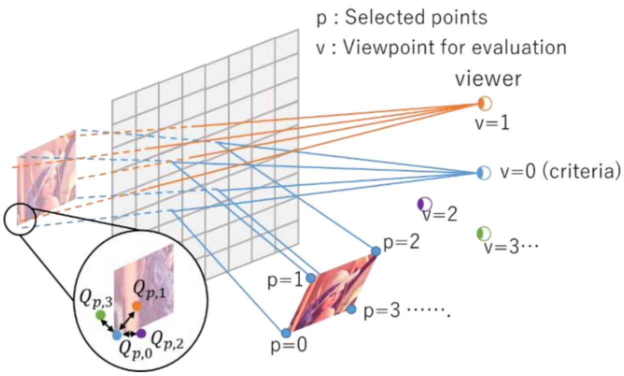


Figure 6 Optimize the display image shape

In this function, we use to calculate the reference viewpoint and multiple viewpoint of the other. The pixels in the display image (Figure 6, p=0~3) are selected and calculate the coordinates which each pixel can be observed from all viewpoints at designed depth. This coordinates hereinafter referred to $Q_{p,v}$. In the $Q_{p,v}$, p represents the number of selected point and v represents number of viewpoints. The difference between the coordinates which view from reference and the other is using for evaluation value.

Simulation

We conduct a computer simulation to confirm which the image distortion and the system can provide a correct motion parallax. We use a ray tracing software "POV-Ray". The specifications are shown in Table 1, 2 and 3.

Table 1 Conditions of display device

Condition	Value
Location	(0.0, 0.0, -1.0)

Table 2 Design conditions of mirror array

Condition	Value
Screen size	2.5×2.5
Number of mirrors	100×100
Virtual image size	1.0×1.0
Virtual image location (z)	2.0

Table 3 Simulation conditions of POV-Ray

Condition	Value
Center viewpoint	(0.0, 1.25, -2.5)
Shift viewpoint	±1.25 (x, y)

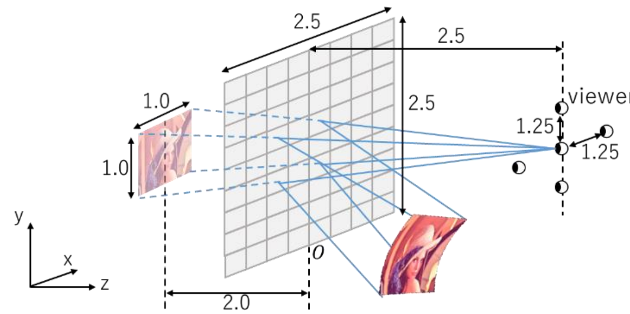


Figure 7 Simulation conditions

In this simulation, we produce the half mirror array screen and display device (display image) and observe the screen from 5 viewpoints. However, it does not verify the transparency of this screen. The observed images from each viewpoint are shown in Figure 8. Also, positional relationship between screen, virtual image and display device is shown in Figure 9.

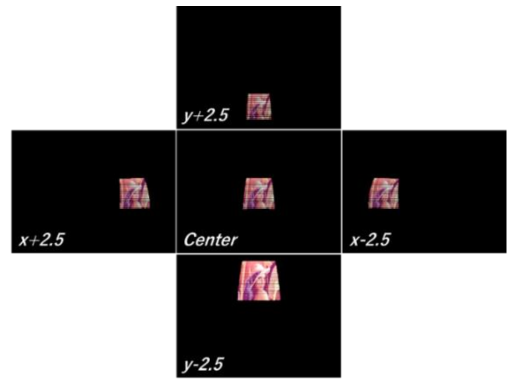


Figure 8 Simulation result

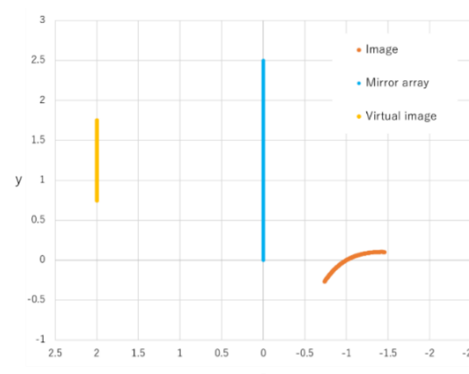


Figure 9 Location relationship

From Figure 8, virtual image distortion when the viewpoint moves to up and down is larger than the viewpoint moves to left and right. Next, we confirm the motion parallax. The result is shown in Figure 10. In this figure, ideal result (white frame) superimposed on the observed image. From this figure, we confirm the observed images are moved same as ideal result. Therefore, it is successful to display the image at designed position.

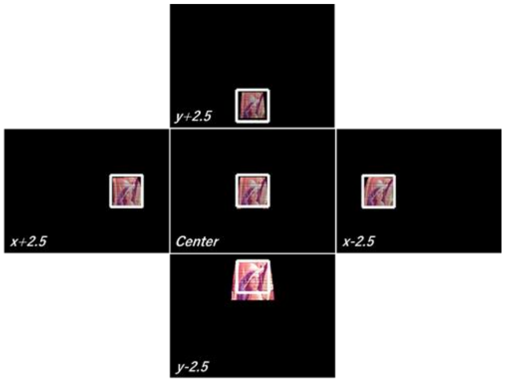
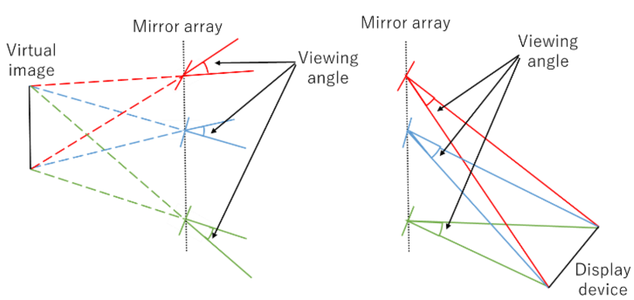


Figure 10 Compared the observed image with ideal image

Discussion

From the simulation result, we confirmed that image distortion when viewpoint moves up and down is larger than left right. In this section, we discuss the method reducing the distortion when viewpoint moves to up and down. First, to select some mirrors in mirror array. Figure 11(a) is shown that which areas can be shown by each mirror. Here we call it "viewing angle per mirror". From figure 11(a), it confirms that viewing angle is different per mirror. The shift amount of referenced pixel when viewpoint moved is different because viewing angle is different per mirrors. Therefore, the virtual image is distorted. If this angle is possible to be same for all mirrors, it takes a guess the distortion can be reduced.

Next, we define the rays from display image to mirror. The rays from display device is drawn like Figure 11(b) because of displaying an entire image at designated area. Angle between the rays from edge of the display image is same for viewing angle because rays reflect on mirror and the reflected rays equal to the solid line part of Figure 11(a). Therefore, viewing angle can be changed which the position of display device is changed.



(a) (b)

Figure 11 Viewing angle

We apply the theorem of circumferential angle to proposed method so as to decide the position of display device. The applying method is shown in Figure 12. It is expected about viewing angles are same for all mirrors by placing the Mirror array and displayed image on a same arc.

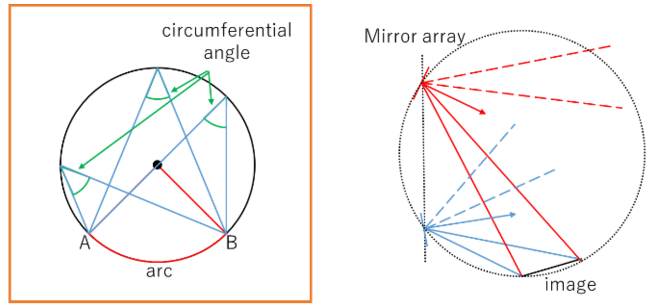


Figure 12 Theorem of circumferential angle

Using an improvement method, the system is reconstructed and confirm the distortion by simulation. Table 2,3 and 4 are shown the simulation parameter.

Table 4 Conditions of display device

Condition	Value
Circle radius	2.5
Off-center (z direction)	0.0

In this simulation, we produce the half mirror array screen and display device (display image) and observe the screen from some viewpoints which specified by us. However, it does not verify the transparency of this screen. The observed images from each viewpoint are shown in Figure 13. Also, positional relationship between screen, virtual image and display device is shown in Figure 14.

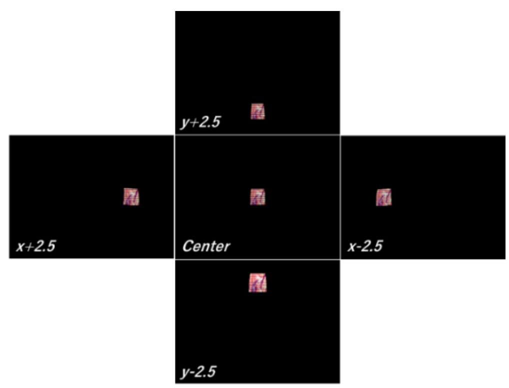


Figure 13 Simulation result

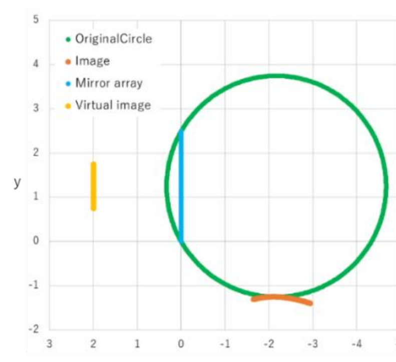


Figure 14 Location relationship

From Figure 13, we confirm that virtual image distortion when the viewpoint moves to up and down is reduced. Next, we confirm the motion parallax. The result is shown in Figure 15. In this figure, ideal result (white frame) superimposed on the observed image. From this figure, we confirmed the observed images are moved same as ideal result. Therefore, it is successful to display the image at designed position. However, size of observed image is become small compared before improvement with it.

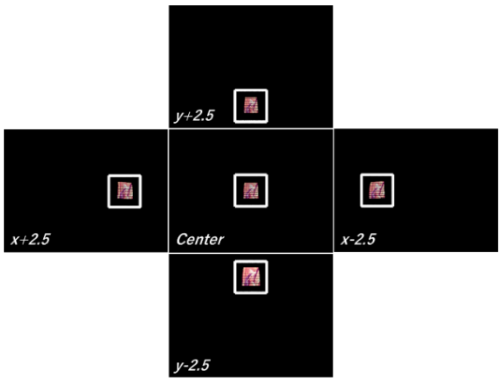


Figure 15 Compared the observed image with ideal image

The cause of this, distance between display device and the screen is longer (compare Figure 9 with Figure 14). In future, we improve the objective function which size of display image is variable corresponding to the distance.

Conclusion

In this paper, we propose a transparent virtual image display using small mirror array which enables multiple viewers to see a similar virtual image same time. The system consists of a display device and a transparent screen which is a window glass incorporates a half mirror array. The screen can be placed vertical on the ground. By optimizing the angle of mirror and position of display device, the image distortion is minimizing which is occurred moving the viewpoint. We conduct a computer simulation to simulate the correct motion parallax is provided. From the result, we confirmed the proposed system can be displayed the virtual image at designed position. Also, image distortion when viewpoint move to up and down can be reduced by the improving method. Future work includes improvement of the objective function of the optimization.

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Author Biography

Akane Temochi received her B.E. from the Nagaoka University of Technology in Niigata, Japan (2018). She is now in master course of Department of Electrical, Electronics and Information Engineering in the same university.