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An Artifact Removal Algorithm for Near-Eye Microlens Array Displays

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An Artifact Removal Algorithm for Near-Eye Microlens Array Displays*

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Abstract

Nowadays, various kinds of head mounted displays are used as output in the virtual reality system. In order to achieve a wide field of view, conventional head mounted display has a large lens, the weight and size can not be ignored when the user is using it. By using microlens array, it is possible to design a lighter and thinner head mounted display. However, when the eyes are close to the display or the pupil size increases, ghost images will be generated. After applying ghost image removal algorithm, it will cause a phenomenon called artifact. In this thesis, we studied the reasons for the formation of artifacts. Then we proposed an algorithm to remove artifacts, we describe the removal algorithm in detail in the thesis. In order to verify the algorithm, we found the parameter settings that are suitable for verification. Finally, we verify the results by setting the parameters. In this way, we checked the results and compared the previous image, the artifacts were removed.

Keywords:

Head Mounted Display, Microlens Array, Virtual Reality, Light Field Display

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1 Introduction

Nowadays, head mounted displays are widely used in virtual reality(VR) system or augmented reality(AR) system. VR has existed for decades. Due to advances in VR tech gradually increasing in commercial applications and is becoming more popular in video games[1]. In this chapter, we first describe the existing head mounted displays, and we will introduce the features of these head mounted displays.Since we are using the near-eye display in this research, so near-eye microlens array display will be introduced in second section. In this section, we will describe structure, imaging principle, pros and cons of the microlens array display. Then in the third section, we will introduce the approach and our idea of this research, and last section is the structure of this thesis.

1.1 Existing head mounted display

The head mounted display (HMD) is a device attached to the head used in the fields such as virtual reality and augmented reality, and is drawing attention in recent years. By using the head mounted display, we are able to experience new experiences in the fields of entertainment, remote collaboration, telepresence, training and so on. At present, there are many kinds of consumer-grade head-mounted displays.

About head-mounted displays, they can be divided into two categories, one is an immersive head-mounted display that is purely used to watch movies. This type of device can only watch the projected movie, can not see the outside world, mainly used to watch video or virtual reality (VR) use. The other type can see the outside world, called a see-through head mounted display(ST-HMD). These displays are primarily used in augmented reality applications, where computer-generated images and information are superimposed on the external world to provide additional information. ST-HMD is divided into Video See-through (VST) and Optical See-through (OST). Those HMD can not see the outside world like Oculus Rift(see Figure 1.1.1) and HTC Vive(see Figure 1.1.2) shows,these two kinds of head mounted display are also now the most popular HMDs in the world.Microsoft has released many mixed reality head mounted displays with many manufacturers, like Samsung HMD Odyssey Windows Mixed Reality Headset(see Figure 1.1.3), ASUS Windows Mixed Reality Headset(see Figure 1.1.4) , etc. These mixed reality displays are all VST-HMDs, because there is a camera on the HMD, it can capture the real scene and display it on the display, so that we can see the real scene through VST-HMD. For OST-HMD, the most famous now is Google Glass(see Figure 1.1.5) and Microsoft's HoloLens(see Figure 1.1.6), these two kinds of head mounted display have a transparent glass on it, by projecting the processed image onto the glass, we can see the real scene and the image through the HMD at the same time.

Figure 1.1.1: Oculus Rift[2]

Figure 1.1.2: HTC Vive[3]

Figure 1.1.3: Samsung HMD Odyssey Windows Mixed Reality Headset[4]

Figure 1.1.4: ASUS Windows Mixed Reality Headset[5]

Figure 1.1.5: Google Glass[6]

Figure 1.1.6: Microsoft Hololens[7]

For these head mounted displays, we can also classify the head mounted display with two parameters:

- Weight
- Field of view(FOV)

Because we need put the HMD on our head, so the weight is a very important indicator of comfort. The field of view is a world that can be seen through vision at any instant. The table 1.1.1 shows the features of existing head mounted displays.

HMD	Display type	weight(g)	FOV(degree)
Oculus Rift	VR	470	94
HTC Vive	VR	555	110
Samsung Gear VR	VR	463	96
Sony PlayStation VR	VR	610	100
Samsung Odyssey MR Headset	VST-HMD	645	110
ASUS MR Headset	VST-HMD	under 400	95
Google Glass	OST-HMD	36	54.8
Microsoft HoloLens	OST-HMD	579	30

Table 1.1.1: Features of existing head mounted display

The weight and size of the HMD depend on the focal length of the lens. Except for the OST-HMD, other HMDs use large lenses, so the weight and size are large.

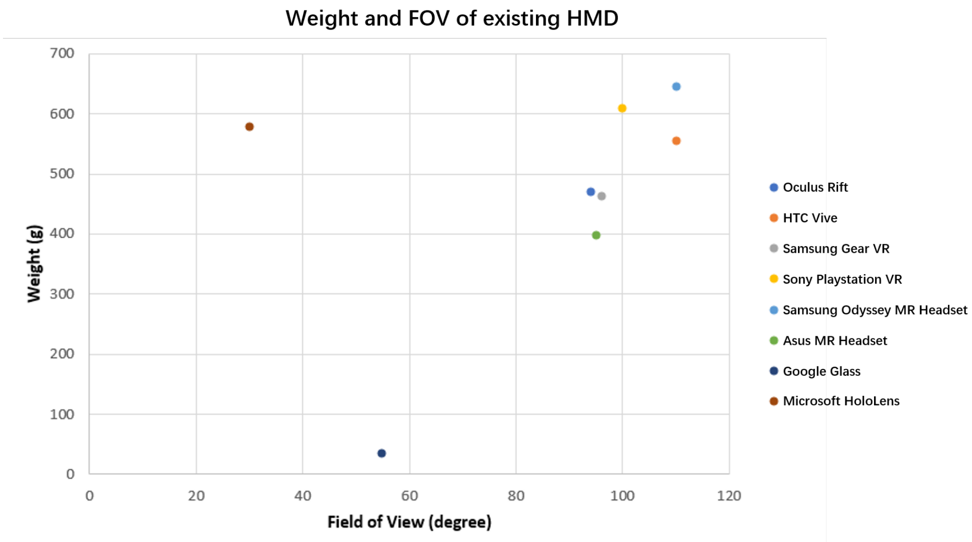

Figure 1.1.7: Weight and FOV of existing HMD

According to the Figure1.1.7, most HMDs can not balance weight and field of view, but for near-eye microlens array display, it can be light weight while having a wide FOV.

1.2 Near-eye microlens array display

We are using a near-eye microlens array display in this research, near-eye microlens array display is a kind of HMD applying light field. These kind of HMD can realize a compact size and a large viewing angle. We will give several examples of HMDs that apply light fields.

- Pinlight Displays
  Andrew Maimone et al.[8] made a see-through augmented reality display prototype by using pinhole array method. The prototype contains two components: an LCD panel and an array of point light sources(see Figure 1.2.1). The size of prototype is very small(see Figure 1.2.2), and could provide 110 degree diagonal field of view. But resolution and luminance are limited due to the pinhole density and the pixel pitch of the display(see Figure 1.2.3).

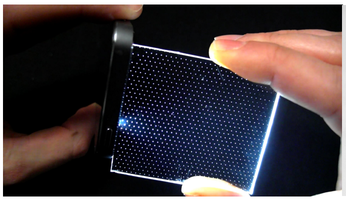

Figure 1.2.1: Pinhole Array

Figure 1.2.2: Pinlight Display

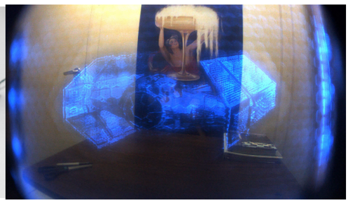

Figure 1.2.3: Field of View

- Multilayer Desktop 3D Displays
  Andrew Maimone et al.[9] made a optical see-through HMD by using a multilayered display. Compared with pinlight display, this HMD can provide wider field of view, and it is possible to selectively give an immersive feeling. However, in the prototype, the resolution is restricted by the number of liquid crystal displays and the pixel pitch, and sharp images can be seen by making it multilayered, but as the number of layers increases, the transparency decreases(see Figure 1.2.4).

Figure 1.2.4: OST-HMD using a multilayered display

- Near-Eye Microlens Display
  Douglas Lanman et al.[10] made a non-transmissive head mount display using a microlens array. Microlens array is a lens array consisting of many tiny lenses, the microlens array is very thin and light. The microlens array is placed on the micro display, and the HMD made with microlens array is very thin and light, and its size is almost the same as that of glasses(see Figure 1.2.5). Compared with the HMD using a single lens, the thickness of HMD using microlens array display is pretty thin(see Figure 1.2.6).

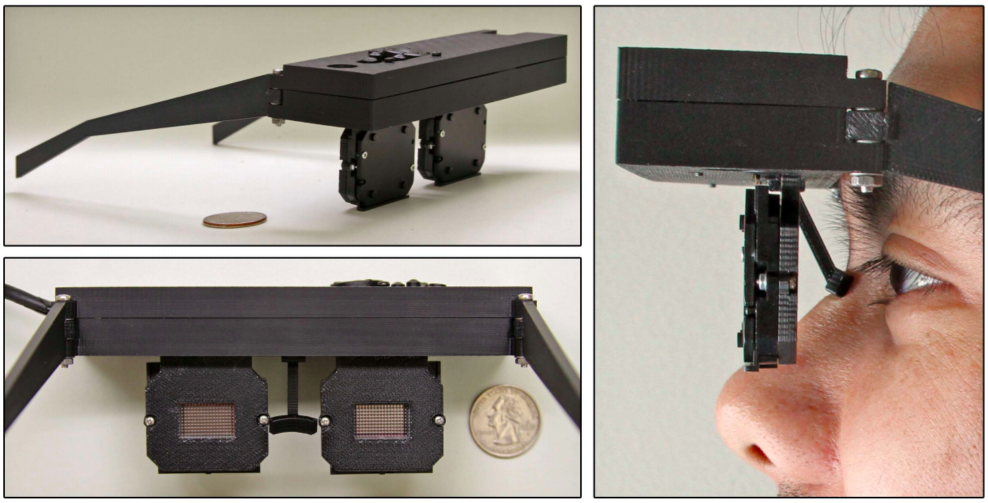

Figure 1.2.5: Head Mounted Near-Eye Microlens Array Display Prototype

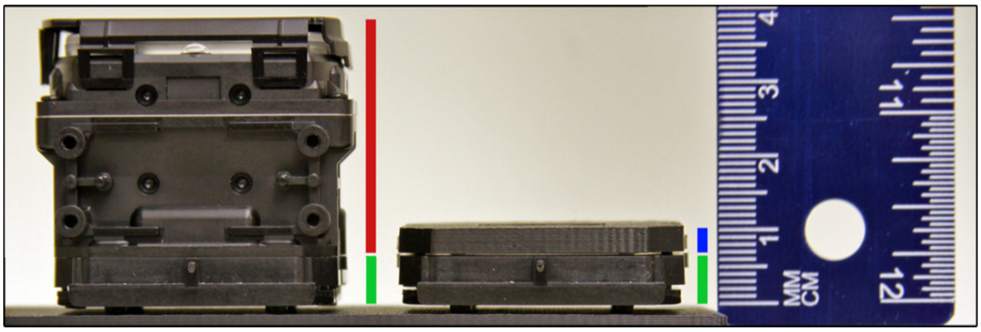

Figure 1.2.6: Thickness of conventional HMD and near-eye microlens display

In this research, we focus on near-eye microlens array display.

1.2.1 Convex lens and microlens array

In this research, we focus on image generation by microlens array method for head mounted display.Therefore, details of image generation by microlens array method and its image generation system are described.

Convex lens

The microlens array consists of many tiny lenses, each of which is based on simple convex lens imaging(see Figure 2.1.1). In the case of a single lens, conventional HMD like HTC Vive has the same structure.

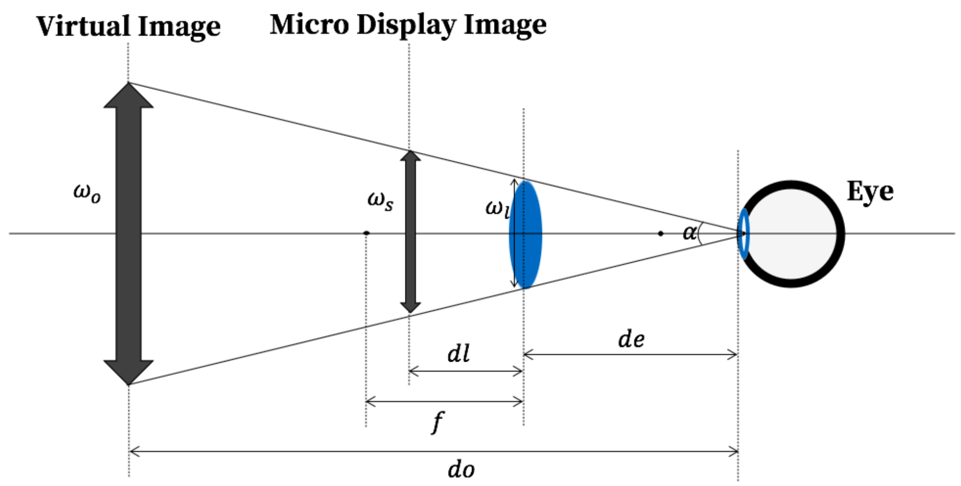

Figure 1.2.7: Convex Lens Imaging

According to the lensmaker's equation[11], The f-number is related to the thickness and the radius of curvature of the lens, so the size of HMD using single lens is also big.

Microlens array

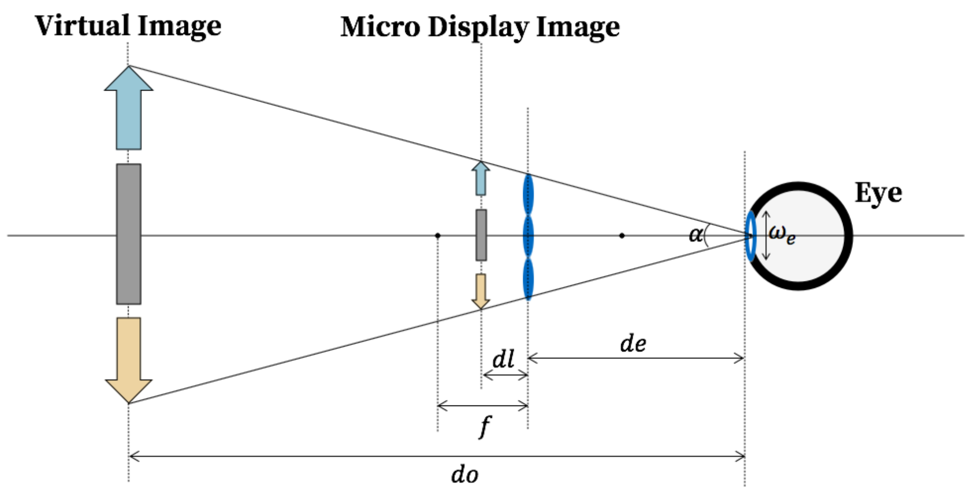

Figure 1.2.8: Microlens Array Imaging

Since the microlens array is an array of lenses, it is partially the same as the case of the single lens of the previous item. According to the lensmaker's equation(2.1.5), the radius of curvature of the lens R_1 and R_2 of microlens array are very small, so that the f-number of the microlens array is getting small. By using this kind of microlens array, we can design thin and light HMD.

1.2.2 Advantages and problems

Advantages

In this research, we focus on microlens array method. First, the microlens array system can realize a compact head-mounted display.
When we are designing a head mounted display, when outputting a virtual image at the same distance, the distance between the display and the lens plane depends on the focal length of the lens. In the case of a single lens method, according to the lensmaker's equation(2.1.5), since the lens aperture is large, the focal length of the lens is also large.
Therefore, the distance of the lens and the display must be increased. In contrast, in the microlens array method, since the lens aperture is small, the focal length of the lens is also small, and compared with the single lens method , It is possible to reduce the distance between the lens and the display, since the distance of the lens and the display can be reduced, the display portion of the head mounted display can be thinned.

Problems

In normal case, light rays emitted by the pixel on the micro display should only pass through only one lens, then pass through the pupil of human beings, then reach the retina, then the pixel could be seen. In this case, we can see only one image at the same time.
However, in some cases, for example, the pupil size is very large, or the eye is very close to the microlens array. For human beings, the pupil size will getting narrow when the environment is light and will getting wide when the environment is dark. The range of the pupil size is 2 to 8 millimeters[12].

Figure 1.2.9: Normal case and ghost image case

Light rays emitted by the pixel will also pass through other lenses, not only the center lens, then reach the pupil, part of light rays will pass through the pupil then reach the retina. In this case, we could see not only one pixel, these kind of images are called ghost images, ghost images could degrade image quality.

Figure 1.2.9 shows an image in a normal case and in a ghost image case. We could see that in the ghost image case, there are two more red G in the image(inside the green boxes).

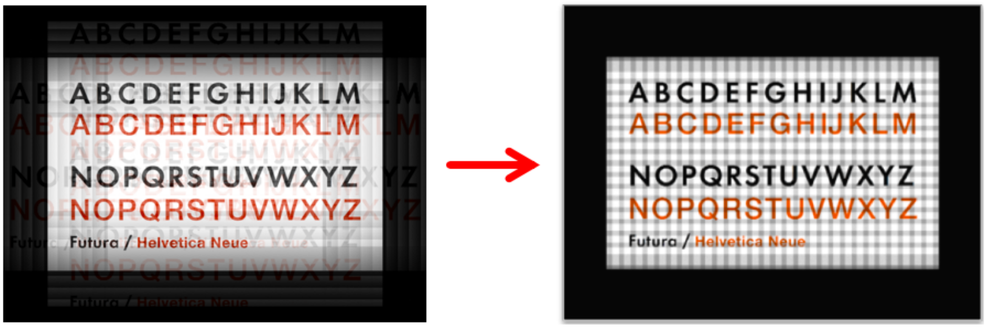

Figure 1.2.10: Ghost image removal algorithm were implemented

My senior Wataru Kashima proposed an idea to remove ghost images [13]. I implemented that algorithm and found that ghost images were removed(see Figure 1.2.10). However, we can see that the brightness of the image is not uniform, many areas are darker than the area next to it, these kind of areas are called artifacts. The cause of artifacts is some pixels were removed when removing ghost images, when light rays are sampling these pixels, these pixels can not get effective values, so the brightness of these part will darker than other part, then we can see artifacts.

1.3 Approach and idea

In this research, I proposed an algorithm to remove artifacts. In order to remove artifacts, the brightness of pixels on the micro display should be changed. Only a part of the pixel brightness can be turned down. If the brightness is turned up, the brightness of the original high brightness pixel will exceed the maximum value, the pixel point will turn white, and the image will change. In this research, an algorithm is proposed to adjust which pixel points need to be changed in brightness, and how much this pixel needs to change. Since we have to check a lot of situations, and need to change a lot of parameters, and it is difficult to change our pupil size in dark environment[12], so it is more suitable to use a simulation to simulate images that we could see, it is easier to compare the results we get. In order to solve this problem, such a two step is required:

1. Microdisplay image and retina image generating system.
2. According to the retina image to change the brightness of the pixels on the microdisplay, then generate new retina image.

1.4 Thesis structure

In chapter 2, we describe related research. In chapter 3, we describe how the ghost image is formed and how the removal algorithm works. In next subsection, some images with artifacts are present and we describe the cause of artifacts. In subsection 3.3, we describe details of the artifacts removal algorithm. In chapter 4, we present the simulation system design and the parameter setting, then present experiment results. In final chapter, conclusion and future work will be given.

2 Related work

In this chapter, we introduce related work, there are two parts, one is how to design optical structure, the other one is image generating system. Mainly we introduce image generating system, this is an important part to the research.

2.1 Optical structure design

Douglas Lanman et al.[10] proposed a structure for microlens array display, so we will describe the optical design.

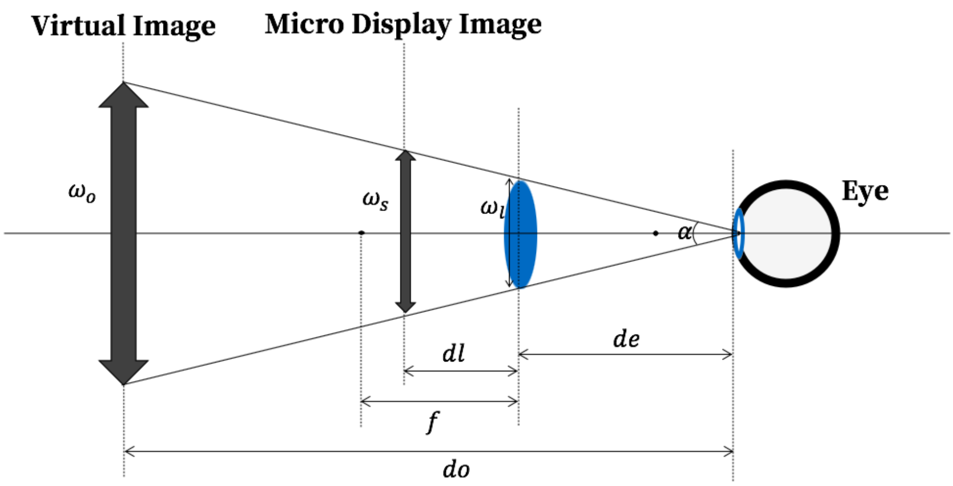

Figure 2.1.1: Convex Lens Imaging

The microlens array consists of many tiny convex lenses, in the case of a single lens, the design is as shown in Figure 2.1.1. The head mounted display using a single lens is a conventional design. d_l is the distance between the lens and the display, f is the focal length, d_e is the distance between the eye and the lens, the size of the display area is w_s, lens size is w_l. With such a structure, the user can see the virtual image by looking at the display through the lens like the figure 2.1.1. Assuming that the distance from the eye to the virtual image d_o, the magnification rate is M, and the size of the virtual image is w_o, the respective values can be obtained as follows[10].

$$\frac{1}{f} = \frac{1}{d_l} - \frac{1}{d_o - d_e},\ for\ 0 < d_l \leq f \tag{2.1.1}$$

$$M = \frac{\omega_o}{w_s} = \frac{d_o - d_e}{d_l} = 1 + \frac{d_o - d_e}{f} \tag{2.1.2}$$

The field of view α is shown as follow:

$$\alpha = 2\arctan\left[min\left(\frac{w_l}{2d_e}, \frac{Mw_s}{2d_o}\right)\right] \tag{2.1.3}$$

And the spatial resolution N_p is:

$$N_p = \left\lfloor \frac{2d_o \tan(\alpha/2)}{Mp} \right\rfloor = min\left(\left\lfloor \frac{d_o w_l}{d_e Mp} \right\rfloor, \left\lfloor \frac{w_s}{p} \right\rfloor\right) \tag{2.1.4}$$

The spatial resolution N_p can be used to design the structure of HMD, affected by the focal length of lens f and width d_l. If we want to design a practical HMD, the focal length and width will be very large. The same conclusion can be obtained by lensmaker's equation as follows:

$$\frac{1}{f} = (n-1)[\frac{1}{R_1} - \frac{1}{R_2} + \frac{(n-1)d}{nR_1R_2}] \tag{2.1.5}$$

The f-number is related to the thickness d and the radius of curvature of the lens R_1 and R_2, we can see that the f-number of conventional single lens is very large due to the R_1 and R_2 are very large. In this case, the size of whole head mounted display will be large, and because of the material, the weight will be heavy.

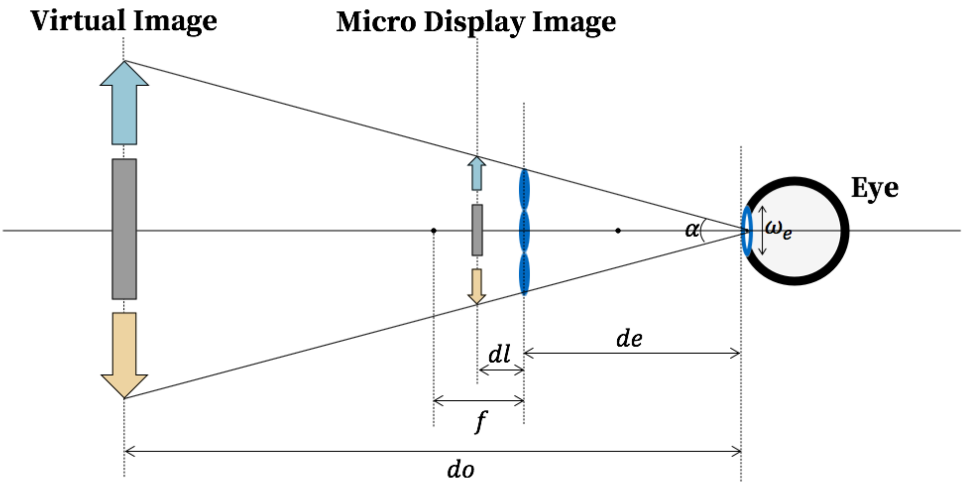

Figure 2.1.2: Microlens Array Imaging

For the microlens array, the structure is shown as Figure 2.1.2. Since the microlens array is an array of lenses, it is partially the same as the case of the single lens of the previous item. By looking at the display through the microlens array, we can see virtual images. If the nunber of lenses is N_l, the field of view α will be:

$$\alpha = 2\arctan\left[min\left(\frac{N_l w_l}{2d_e}, \frac{Mw_s}{2d_o}\right)\right] \tag{2.1.6}$$

The spatial resolution will be:

$$N_p = \left\lfloor \frac{2d_o\tan(\alpha/2)}{Mp} \right\rfloor = min\left(\left\lfloor \frac{d_o N_l w_l}{d_e M p} \right\rfloor, \left\lfloor \frac{w_s}{p} \right\rfloor\right) \tag{2.1.7}$$

In this step, we can set part of parameters for the system to simulate microdisplay image and retina image, these parameters are set as the Table 2.2.1:

Table 2.1.1: Parameters

Parameter	Value
Pitch of lens w_l	1.0 mm
Lenses number N_l	14×8
Focal length f	2.82016 mm
Virtual image distance d_o	400 mm
Distance between microlens array and micro display d_l	2.8 mm

2.2 Image generating system

Based on the optical structure, we can design an image generating system. The original rendering method by Douglas Lanman does not account for pixels on the HMD screen being seen through multiple lenses of the microlens array[13].

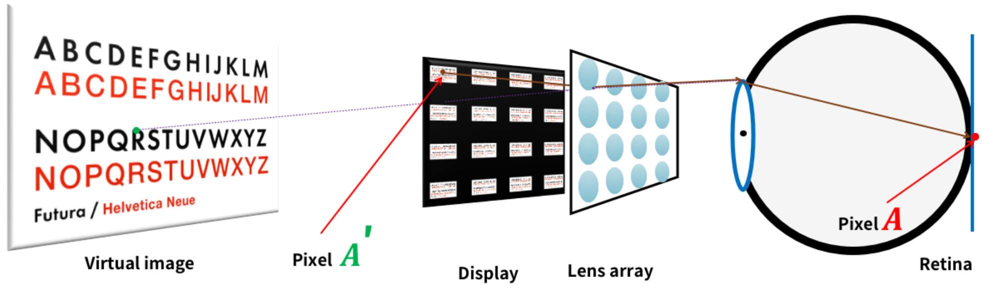

Figure 2.2.1: Single ray imaging path

First, we focus on only one pixel, the pixel A, on the retina(see Figure 2.2.1), and the corresponding pixel A' on the micro display. To generate this pixel A, we need some steps as follows:

1. Get the coordinates of pixel A on the retina, store the coordinates as x_{im}.

2. According to the distance from the retina to the eye lens d_{im} and the distance from the eye lens to the microdisplay image d_o, we can calculate the

coordinates of corresponding pixel on the virtual image, also we store the value as x^v, the equation is:

$$x_v = -\frac{d_o}{d_{im}} * x_{im} \tag{2.2.1}$$

3. Select a random position on the eye lens, store the position as x_{el}, then the intersection of the light ray and the microlens array is x_l, calculate the position by using the equation:

$$x_l = x_{el} + \frac{d_e}{d_o} * (x_v - x_{el}) \tag{2.2.2}$$

4. According to the position x_l, we can get the microlens center x_{lc}, then we can calculate the position of the corresponding pixel on the micro display A', we save the value as x_d:

$$x_d = x_l + \frac{d_l}{d_o - d_e} * (x_v - x_l), d_l = f_l * \frac{d_o - d_e}{f_l + (d_o - d_e)} \tag{2.2.3}$$

5. Sample RGB values of pixel A' as the values of the pixel A.

These steps are only for generating one pixel on the retina and there is only one lens we are using. When we are using microlens array, there are a lot of pixels on the retina, and there are a lot of corresponding positions on the micro display, to generate one pixel on the retina, we have to sample not only one time in case that there are some pixels are not sampled(see Figure 2.2.2).

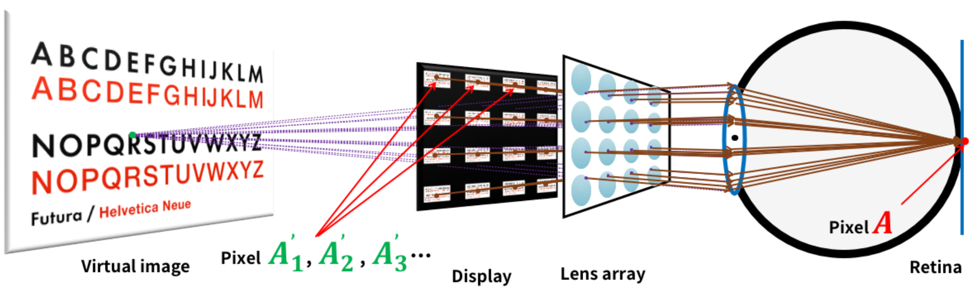

Figure 2.2.2: Sampling when using a microlens array

So the steps for generating pixel on the retina when using microlens array is shown as follows:

1. Find the coordinates of pixel A on the retina.
2. Calculate the corresponding position of pixel A on the virtual image, the equation is the same as equation 2.2.1.
3. Select a random position on the eye lens, calculate the intersection position of the light ray and the microlens array x_l as the equation 2.2.2.
4. Calculate the position of the corresponding pixel on the micro display A', save the value as x_d by using the equation 2.2.3.
5. Repeat steps 2 through 4, in this research, we repeat 1024 times for each pixel on the retina.
6. Add all sampled RGB values together, then divide by the total number of samples, the result is the value of pixel A.

According to the image generating system, some parameters could be confirmed as follows:

Table 2.2.1: Parameters

Parameter	Value
Pitch of micro display w_l	0.012 mm
Micro display resolution	1280×720 pixels
Retina image resolution	1280×960 pixels
Pitch of retina p_{im}	0.009 mm
Pupil size	2∼8 mm

3 Algorithm for artifacts removal

In this chapter, we first describe the cause of ghost image and the ghost image removal algorithm, then we present some images with artifacts under different conditions, then we describe the cause of artifacts. Finally, we will describe algorithm for removing artifacts in section 3.3.

3.1 Ghost image

As we mentioned in section 1.2.2, ghost images may appear in some cases(see Figure 1.2.9), like the pupil size is getting large or the distance between the eye and the lens plane.

3.1.1 Cause of ghost image

Firstly, we focus on only one pixel on the retina and one pixel on the micro display, also we are only focusing on one lens now(see Figure 3.1.1).

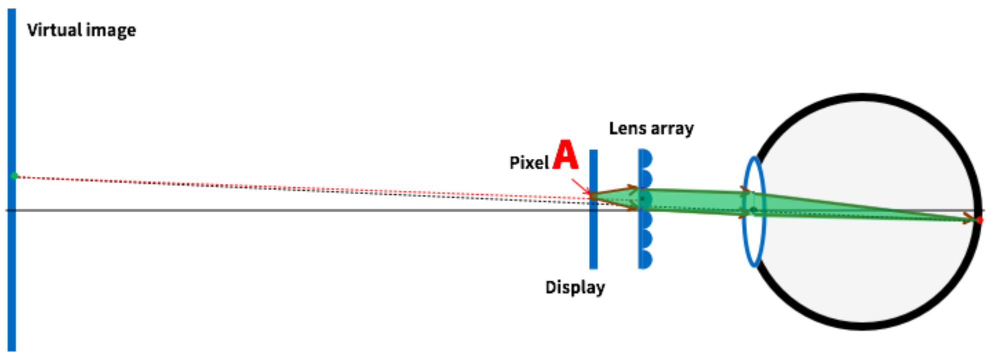

Figure 3.1.1: Normal case

In normal case, light rays emitted by pixel A on the micro display pass through the corresponding lens, then pass through the pupil and reach the retina, then we can see this pixel, and we should see only one pixel. However, in some cases, ghost images could appear, like figure 3.1.2 shows.

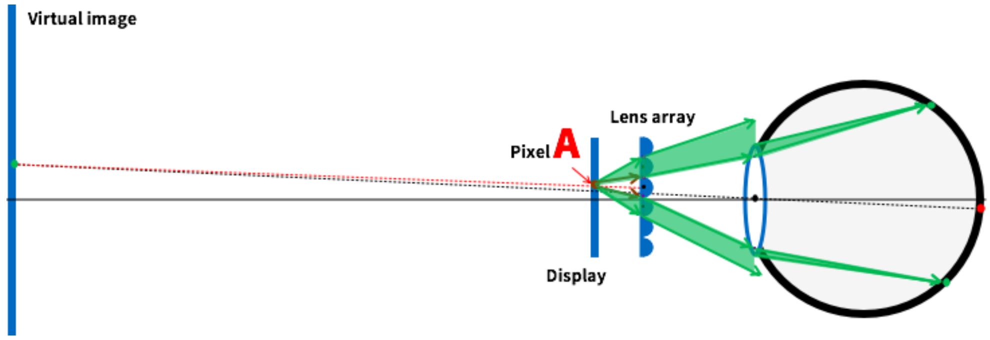

Figure 3.1.2: Ghost image case

Light rays emitted pixel A pass through the next lenses(not the center lens) reach the pupil, part of light rays pass through the pupil and reach the retina, then we can see these pixels. In ideal case, we always hope to see only one image, if we can see more than one image at the same time, these images will overlap, and the image will become blurred(see Figure 3.1.3 and Figure 3.1.4).

Figure 3.1.3: Image with no ghost image

Figure 3.1.4: Image with ghost images

3.1.2 Ghost image removal algorithm

Ghost image removal algorithm is based on the cause of ghost image generation(Figure 3.1.4). If light rays emitted by a pixel on micro display pass through multiple lenses, and pass through the pupil at the same time, we don't use this pixel, that is means we set this pixel on the micro display as a black pixel, the RGB-value of this pixel is (0, 0, 0).

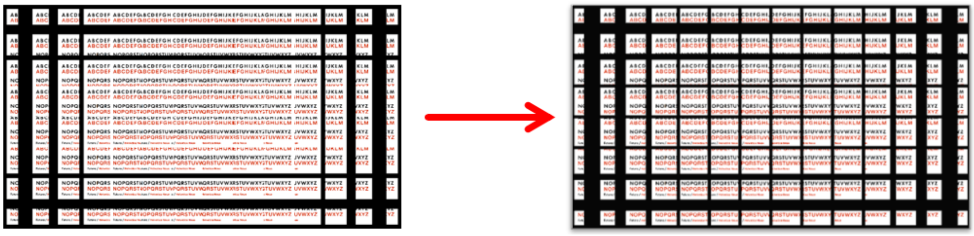

Figure 3.1.5: Micro display image after removing ghost images

By applying for this algorithm, some pixels on the micro display are removed(see Figure 3.1.5). As the result, ghost images are removed(see Figure 3.1.6).

Figure 3.1.6: Retina image after removing ghost images

However, the brightness of the image becomes not uniform, some parts are darker than other parts, for these parts, we called them artifacts. In the next section, we will describe the cause of artifacts generation.

3.2 Artifacts

In this section, we show some images with artifacts under different conditions, then explain the cause of artifacts, finally we describe algorithm for removing artifacts.

3.2.1 Artifacts under different conditions

In this section, we present three set of images(see Figure 3.2.1, Figure 3.2.2 and Figure 3.2.3). The left figure shows the microdipaly image, the right side is the retina image. The different parameters of these images are the pupil size and the distance between eye plane and micro lens array. The other same parameters are shown as follows.

Table 3.2.1: The same parameters in the three sets of images

Parameter	Value
Pitch of micro display w_l	0.012 mm
Pitch of retina p_d	0.012 mm
Lenses number N_l	14×8
Focal length f	2.82016 mm
Virtual image distance d_o	400mm
Micro display resolution	1280×720 pixels
Retina image resolution	1280×960 pixels
Pitch of retina p_{im}	0.009 mm

For figure 3.2.1, the parameters not included in Table 3.2.1 are as follows:

Table 3.2.2: Other parameters for Figure 3.2.1

Parameter	Value
Eye relief d_e	15mm
Pupil size	6 mm

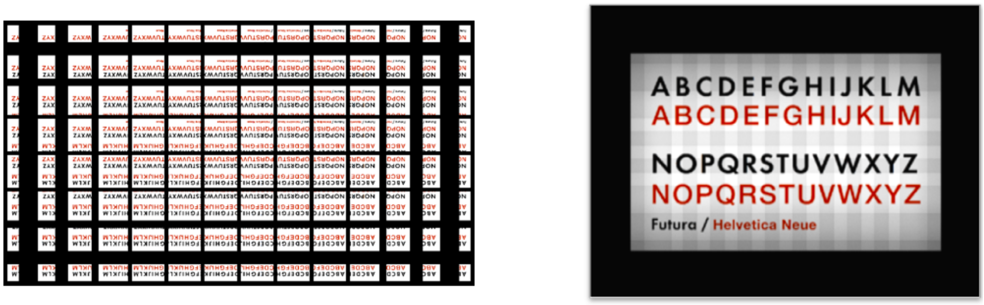

Figure 3.2.1: Image with artifacts

For figure 3.2.2, other parameters are shown as follows:

Table 3.2.3: Other parameters for Figure 3.2.1

Parameter	Value
Eye relief d_e	15mm
Pupil size	9 mm

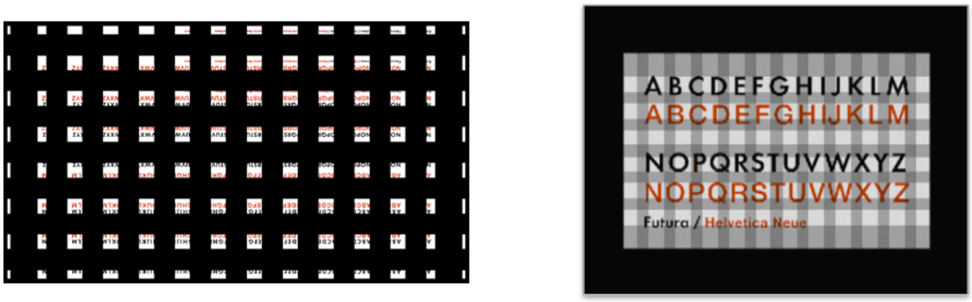

Figure 3.2.2: Image with artifacts

For figure 3.2.3, other parameters are shown as follows:

Table 3.2.4: Other parameters for Figure 3.2.1

Parameter	Value
Eye relief d_e	20mm
Pupil size	9 mm

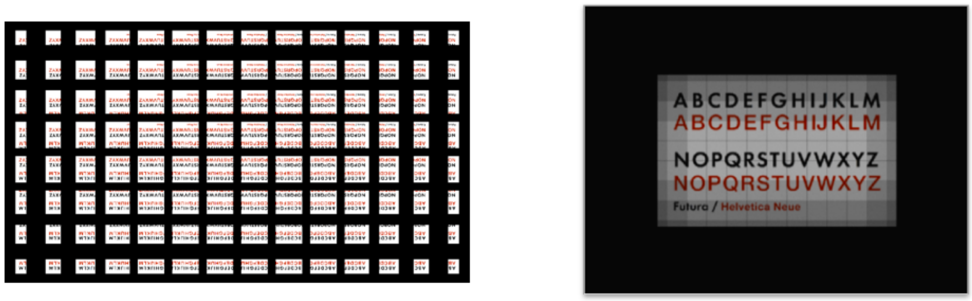

Figure 3.2.3: Image with artifacts

We can find that the closer the eyes are to the display, the wider the artifacts are.

3.2.2 Cause of artifacts

In chapter 2, we mentioned that if we want to generate a pixel on the retina, we have to sample many pixels on the micro display. In ideal case, these sampled pixels are not removed, each sample can get a RGB value. As we know, we removed many pixels due to the ghost image, so it is possible to sample these removed pixels when sampling.

Because we have to divided by the sampling time, so the brightness of these pixels on the retina will be darker than other pixels, then the brightness of whole image is not uniform, then we can see the artifacts.

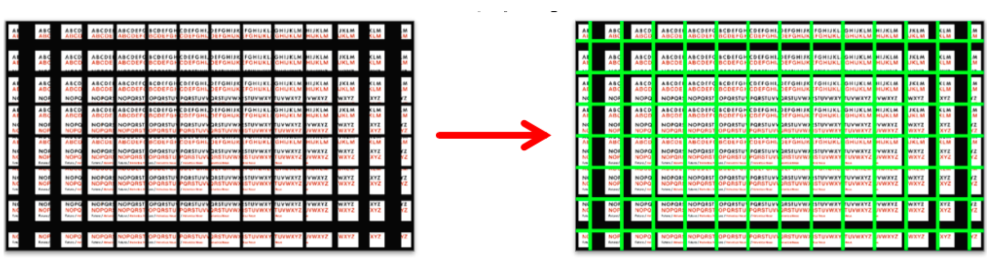

Figure 3.2.4: Pixels are removed removing ghost images

In figure 3.2.4, we use the green pixels to represent the pixel used to remove the ghost images. In other words, when sampling, some pixels on the retina sample pixels on the micro display are in the green area(see Figure 3.2.4), and the green area pixels are the pixels we used to remove the ghost images. So when sampling, the sampled RGB values of these samples are(0, 0, 0), that is a black pixel.

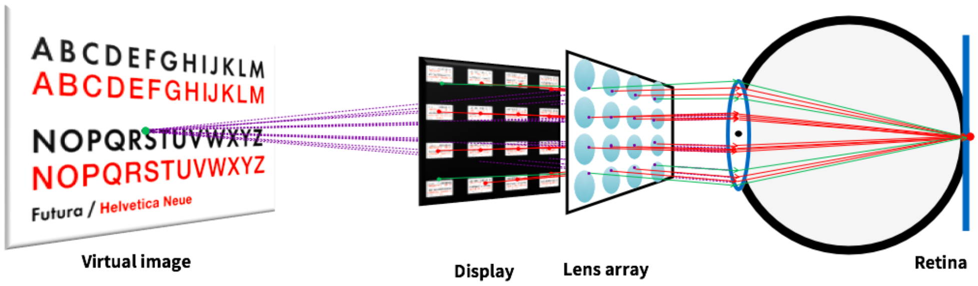

Figure 3.2.5: Pixels with invalid samples

In figure 3.2.5, we can easily understand why artifacts appear. When we are generating a pixel on the retina, we need a lot of light rays for sampling. In ideal case, all of light rays should be effective sample. But if it is an invalid sample(the green light rays in figure 3.2.5), will return a zero value when sampling, then the brightness of this pixel will darken.

3.3 Algorithm for removing artifacts

We proposed an algorithm to remove artifacts and the algorithm will be described in this section. We can not change the brightness of those pixels on the micro display are used to remove the ghost, because the brightness of these pixels are zero, if we change the brightness, image we see will be changed. In this case, we can change the brightness of the rest pixels, it should be noted that not all pixels need to be changed in brightness.

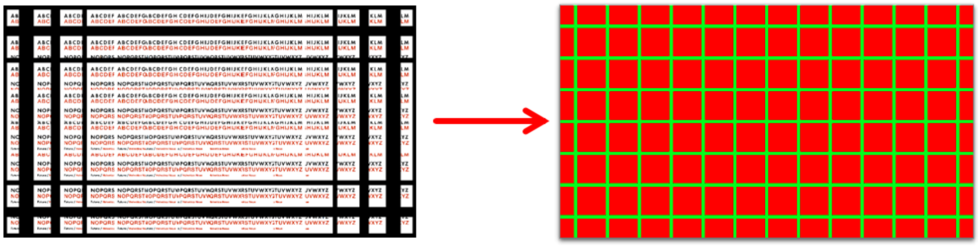

Figure 3.3.1: Distinguish between two kinds of pixels

First, we need to classify pixels on the micro display into two kinds, one is the pixels are removed to remove ghost images, we use green to represent, and we set flag 0 to them, the others we use red to represent, and we set flag 1 to them, like Figure 3.3.1 shows.

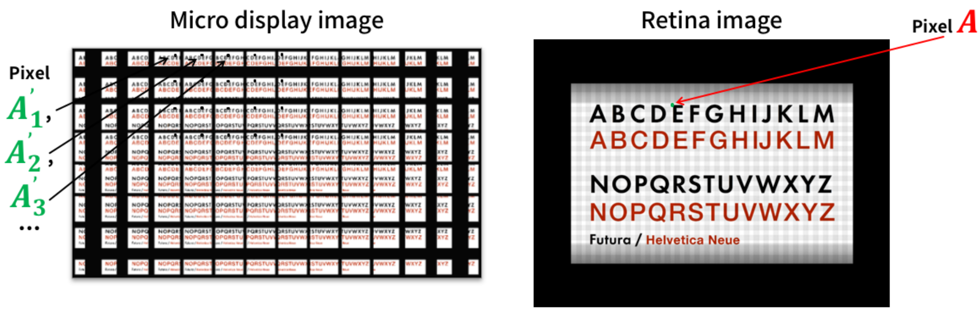

Figure 3.3.2: Pixel A and the corresponding pixels on the micro display

Second is to sample and count effective samples, we use pixel A as an example. When we are generating pixel A, we can find many corresponding pixels on the micro display, like A'_1, A'_2, A'_3 and so on. Each sample will sample one of these pixels, sampling is not ordered, but random. The location of those sampled corresponding pixels may be in the position flag 0, in this case, we get an invalid sample. Then we count those effective samples, when the sampling is over, we can get the total number of effective samples, save this total number for each pixel, we will use it later.
When the points on the retina image are all sampled, each point has a total number of valid samples, we need to find the minimum number of them.
We mentioned in Chapter 3 that we sample 1024 times for each retina pixel,

artifacts are because the brightness of the pixels on the image are different. When sampling, some sample light rays of those darker pixels are go to the area where pixels are removed for removing ghost images, these samples will sample black pixels, then enhanced the brightness. So we have to adjust the brightness of pixels on the micro display, and we need a equation as follows:

$$New\,brightness = Original\,brightness * \frac{minimum\,number}{Flag\,1\,number\,of\,current\,pixel} \tag{3.3.1}$$

According to this equation, we can calculate the new brightness for pixels on the micro display. However, the minimum number might be zero, so we have to set a limitation for it. If not, the brightness of all pixels will become zero, the whole microdisplay image will be black.
So the whole algorithm is as follows:

1. Classify pixels on the micro display into two kinds, set flag 0 for those pixels are removed for removing ghost images, set flag 1 for other pixels.

2. For each pixel on the retina image, sample and count the number of effective samples, save the total number.

3. Find the minimum number of step 2, if the minimum number is zero, set a limitation for it.

4. Adjust the brightness of pixels on the micro display image according to the equation 3.3.1.

The whole algorithm is finished, but when we studied further, we found a problem. In ideal case, different pixels on the retina should sample different pixels on the micro display.

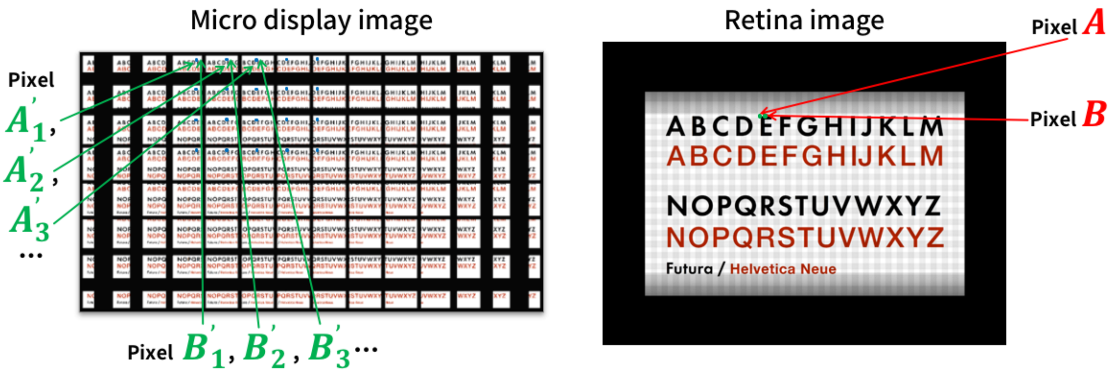

Figure 3.3.3: Multiple pixels are sampling the same pixel

For example, in Figure 3.3.3, there is a pixel A on the retina image, the corresponding pixels on the micro display image should be A'_1, A'_2, A'_3 and so on. The pixel B on the retina is the pixel next to the pixel A, so the corresponding pixels on the micro display image should be B'_1, B'_2, B'_3 and so on. These B'_n pixels should be the next pixels of A'_n in ideal case.

However, The distance between those corresponding pixels is too close, in Figure 3.3.3 case, is only 0.18 dot pitch. In other words, the distance between the pixel A'_1 and pixel B'_1 is less than 1 dot pitch. When we are sampling, the pixel B is not sampling pixel B'_1, B'_2, B'_3, pixel B is sampling A'_1, A'_2, A'_3 and so on. In this case, there are two problems:

- The equation 3.3.1 could not work.
- The retina image will be blurred.

For each pixel on the micro display image, there are more than one corresponding pixel on the retina image. Considering this problem, we add two situation to deal with it:

1. When calculate new brightness for the pixel on the mirco display, use the sample number of only one pixel on the retina image.
2. When calculate new brightness for the pixel on the mirco display, use the average value of all corresponding pixels on the retina image.

Of course in these two cases, if the minimum number goes to zero, we still to set a limitation for it.

4 Experiment

In this chapter, we first introduce simulation, in the simulation, we introduce system design and parameter setting. Finally we will represent results.

4.1 Simulation

Because it is difficult to use a test to check the results in reality, there are many reasons, like we can not change our pupil as we want, or it will take a lot of time to build a real object to simulate human's eyeball. So we use simulation to check results in this research. The simulation system consists of two parts, the first part was created by Arno Lubke in the doctoral course of Nara Institute of Science and Technology, the second part is created by myself. The first part is generate micro display image and retina image, the second part is to generate ghost image removed micro display image and retina image and artifacts removed micro display image and retina image.

4.1.1 System design

Read an original image and output the micro display image based on micro lens array structure, in this step, we add a function to check whether ghost image could appear, we removed pixels on the micro display could lead to ghost images, then according to the micro display image we generate retina image. The method of generating Retina image is described in detail in Section 2.2.

The flow is shown as follows:

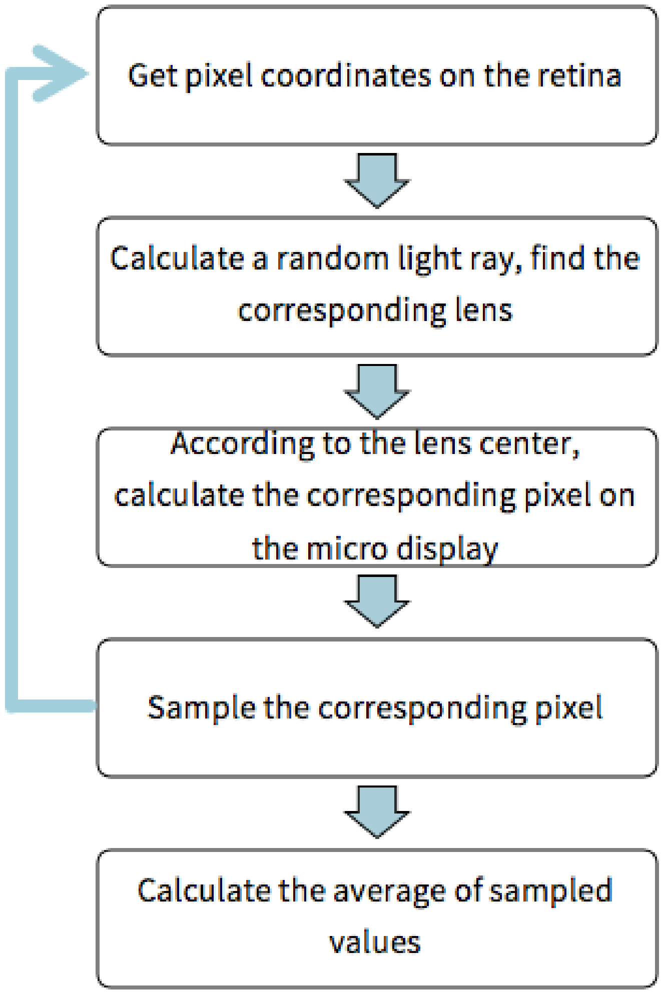

Figure 4.1.1: Process for generating retina image

In this step, we also record effective sampling number for each pixel on the retina image. According to these retina image and the data we record, we can generate a new micro display image, then according this new micro display image, we can generate a new retina image.

The process is shown as follows:

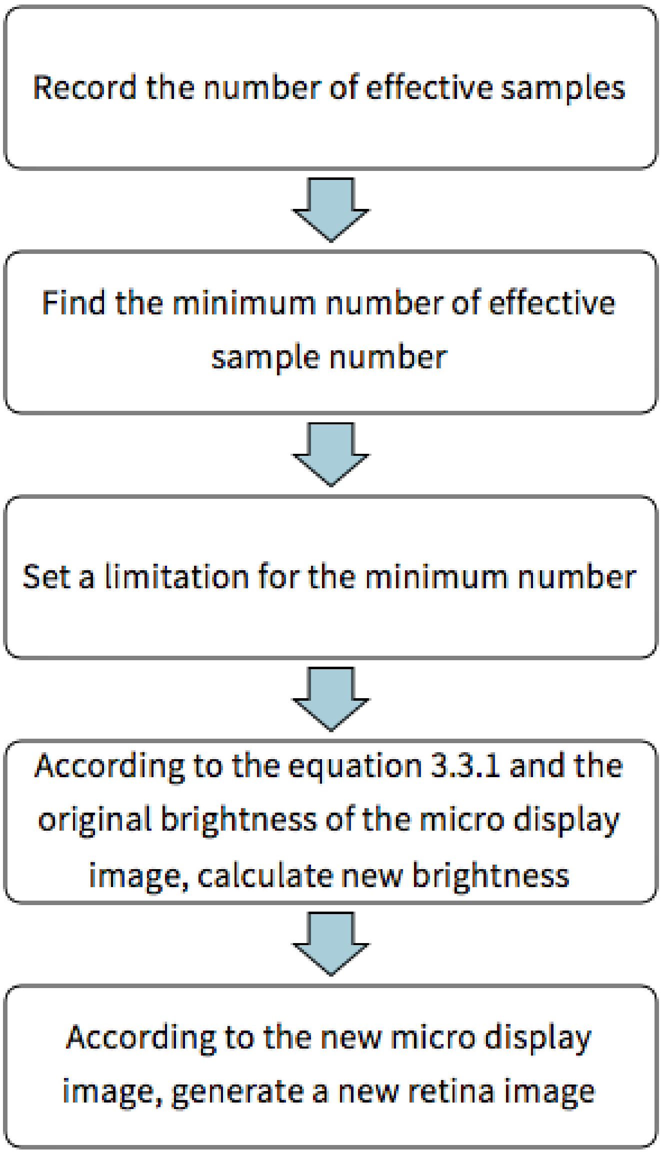

Figure 4.1.2: Process for artifacts removal algorithm

By using this simulation, we can get four images in total at the same time, includes a microdisplay image(ghost images algorithm applied), a retina image(ghost image removed), a new microdisplay image(artifacts removal algorithm applied), a new retina image(artifacts removed).

4.1.2 Parameter setting

We will setting parameters for this simulation system, we list a table as follows:

Table 4.1.1: Parameters setting

Parameter	Value
Pitch of lens w_l	1.0 mm
Pitch of micro display p_d	0.012 mm
Lenses number N_l	14×8
Focal length f	2.82016 mm
Virtual image distance d_o	400mm
Eye relief d_e	15mm
Distance between microlens array and micro display d_l	2.8 mm
Micro display resolution	1280×720 pixels
Retina image resolution	1280×960 pixels
Pitch of retina p_{im}	0.009 mm
Pupil size	6 mm

In section 3.2.1, we have three set of images, the most obvious thing about artifacts is Figure 3.2.2, but too much pixels are removed because of the ghost images, so it is not suitable to as an image of the comparison result. In this case, we choose Figure 3.2.1, the eye relief is 15 millimeters and the pupil size is 6 millimeters.

And if we want to check the artifact removal algorithm, the best choice is to use a white image, if the brightness of two pixels are different, we can easily find the location. So in this research, we also add a white image to test.

4.2 Result

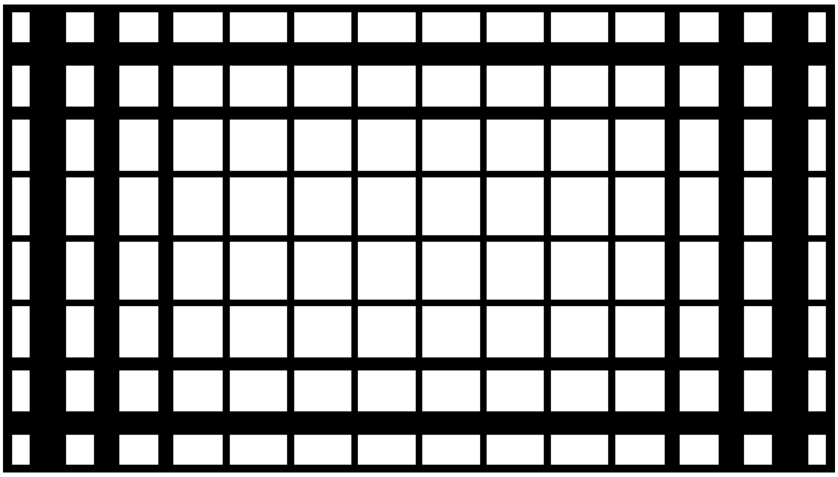

Figure 4.2.1: Original microdisplay image-White image

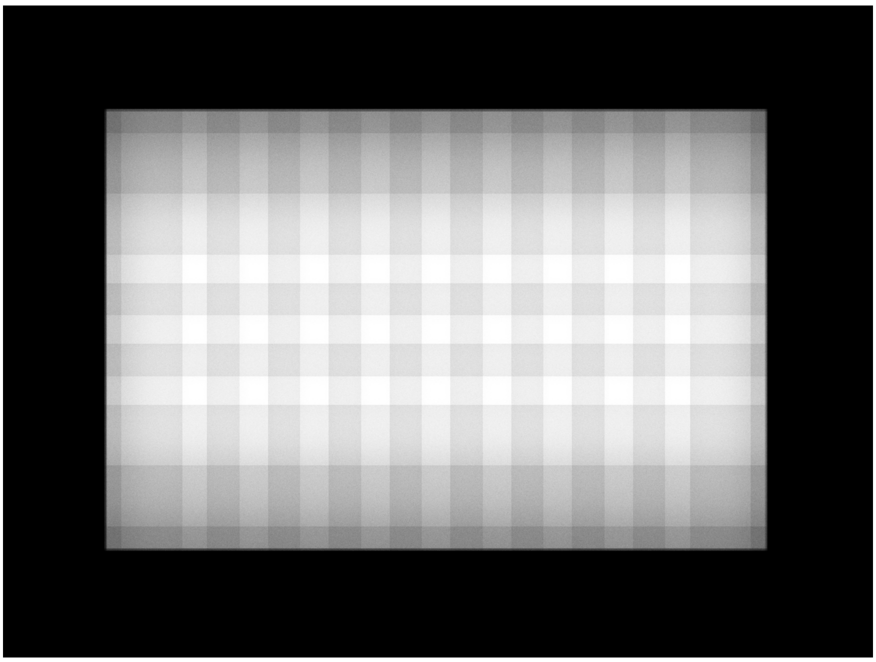

Figure 4.2.2: Original retina image-White image

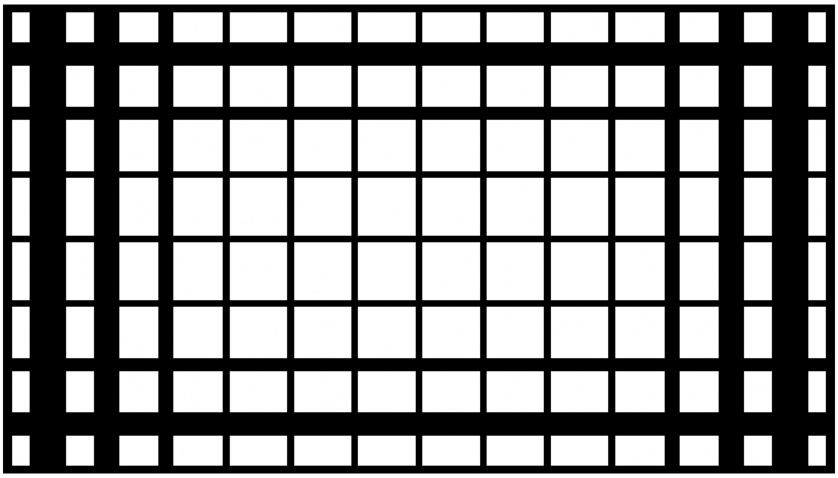

Figure 4.2.3: Micro display image with artifact removal algorithm applied-White image(average value)

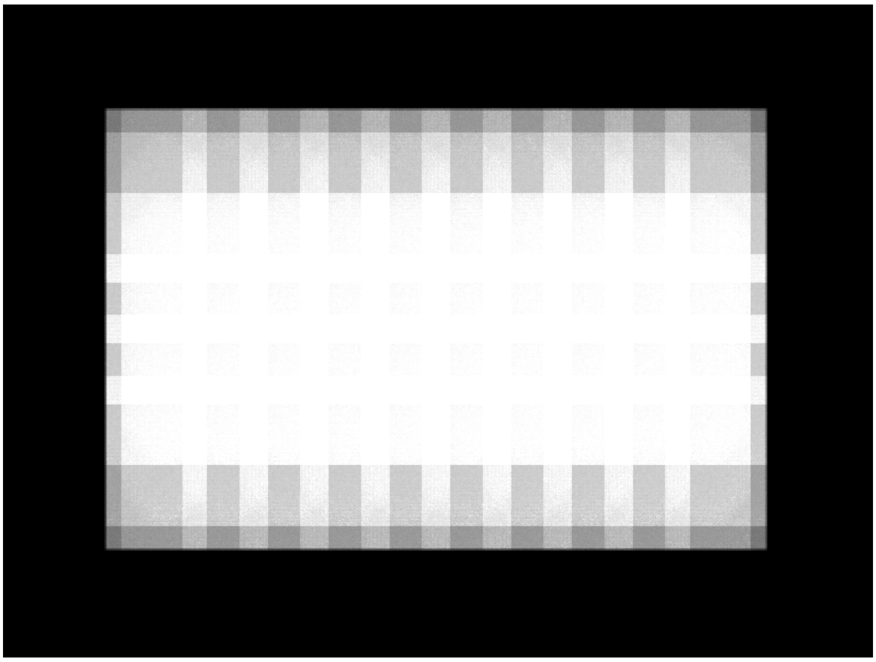

Figure 4.2.4: Retina image with artifact removal algorithm applied-White image(average value)

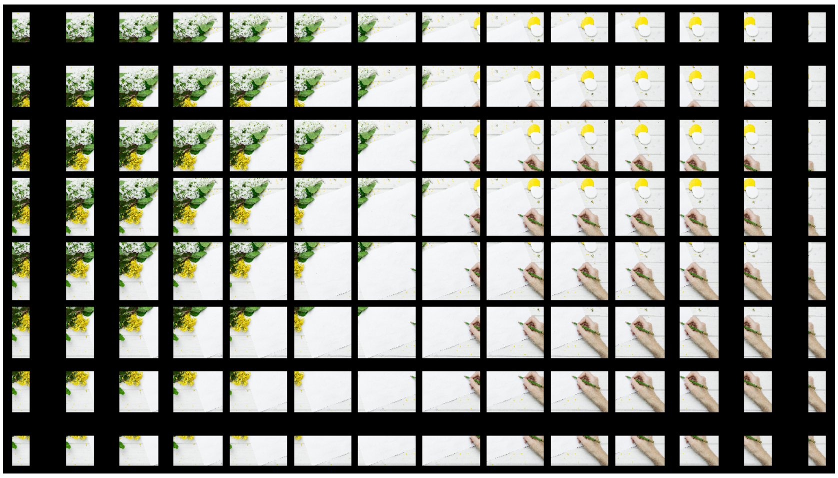

Figure 4.2.5: Original microdisplay image-Image1

Figure 4.2.6: Original retina image-Image1

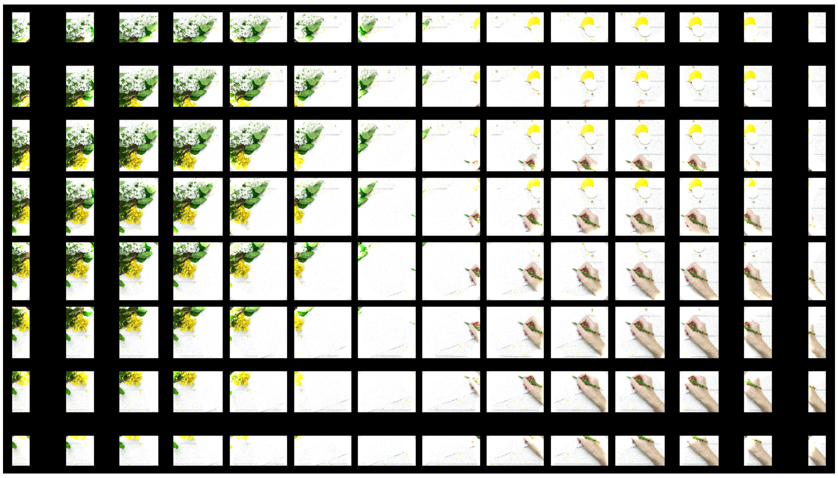

Figure 4.2.7: Micro display image with artifact removal algorithm applied-Image1(average value)

Figure 4.2.8: Retina image with artifact removal algorithm applied-Image1(average value)

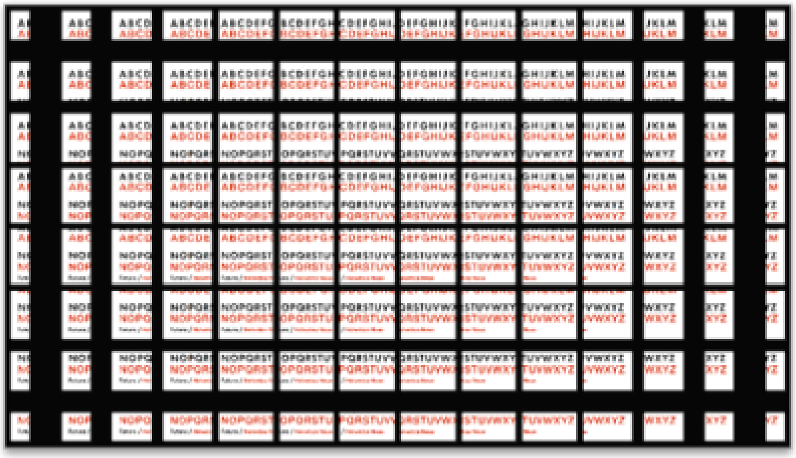

Figure 4.2.9: Original microdisplay image-Image2

Figure 4.2.10: Original retina image-Image2

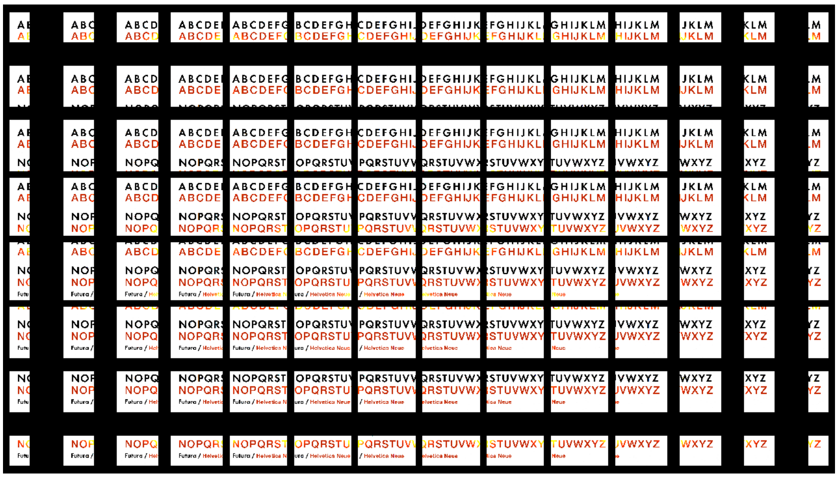

Figure 4.2.11: Micro display image with artifact removal algorithm applied-Image2(average value)

Figure 4.2.12: Retina image with artifact removal algorithm applied-Image2(average value)

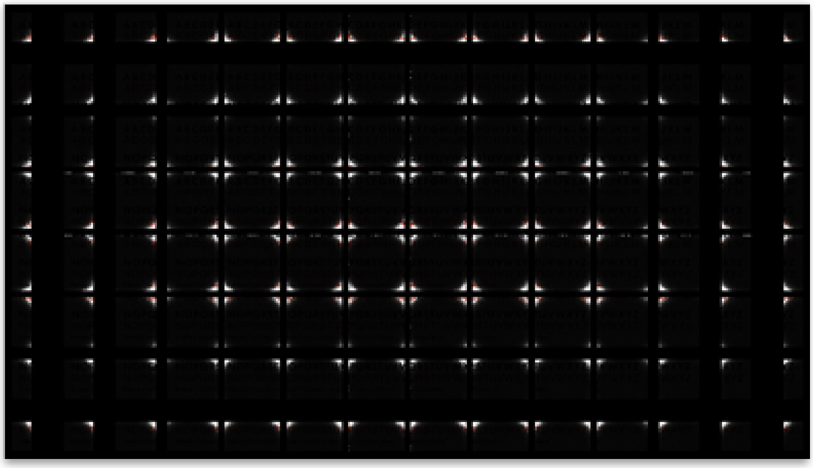

Figure 4.2.13: Micro display image with artifact removal algorithm applied-Image2(one value)

Figure 4.2.14: Retina image with artifact removal algorithm applied-Image2(one value)

4.3 Discussion of results

Firstly, we focus on the white image case. As mentioned in previous chapter, it is easy to check brightness when we are using a white image. The Figure 4.2.1 is the microdisplay image when we are not implement the artifact removal algorithm, and the Figure 4.2.2 is the retina image of it. In the Figure 4.2.2, we can see the brightness is not uniform, we pay attention to the middle part, because the edge of the picture will be affected by many factors, so the quality will be very poor. The Figure 4.2.3 is the microdisplay image when we implemented the algorithm, and the Figure 4.2.4 is the retina image. We can see that the central part of the picture is more uniform in brightness and the artifacts are improved. In this case, we are using average value.

In Figure 4.2.5 and Figure 4.2.6, we used a normal image to check the result, and they are the results when we are not using the algorithm. Then Figure 4.2.7 and the Figure 4.2.7, they are the results when we implemented the algorithm, we can see that the artifact problem of the central part is better than them in the Figure 4.2.5 and the Figure 4.2.6. At the same time we should pay attention that some areas of the picture have changed color, and these areas are concentrated on the edge, this is because these areas do not sample enough pixels and the color will be darker than other areas.

In the Figure 4.2.9 and the Figure 4.2.10, this is the third set of image, we also can see the artifact problem is better when in the Figure 4.2.12. In this case we are using average value. We also checked results when we are using the one value, in Figure 4.2.14, although the artifact problem has improved to some extent, the image quality loss is too serious. This is because when we are using only one value, the number of pixels sampled is too random, and the brightness range of adjacent pixels will vary greatly.

About the limitation in the equation 3.3.1, in fact, limitation can seriously affect image quality. If the limitation is too small, the brightness of the darker part cannot be adjusted to be the same as other parts, thus the brightness difference still exist, the artifact cannot be removed. When choosing the limitation, we should try more times and choose the suitable limitation to get the best results.

5 Conclusion

In this research, we proposed an algorithm for removing artifacts in microlens array displays and checked results. By using microlens array, it is possible to design a light and thin head mounted display. However, the ghost image problem will affect the user experience. To solve this problem, ghost image removal algorithm was applied. Although the ghost images are removed, artifact problem has emerged. To solve artifact problem, we explored the causes of artifacts, then proposed an algorithm to solve this problem. For checking results, we use a simulation to simulate the real structure, because the real model is difficult to make. Then we design a image generating system to generate microdisplay images and retina images we need. Finally we checked the results to verify the feasibility of the algorithm.

Algorithm is feasible, but we still need many future works to do. Because the artifact removal algorithm could lead to the image quality get worse, we still need a new way to find a balance between quality and artifacts.

In this research, the eyeball is in a fixed position, the eyeballs of human beings are not always in fixed position, so it is necessary to consider the condition of eye movement.

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