整合柵狀偏光片和延遲片之新型前投影式3D顯示器

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摘　要

為了得到更自然的立體影像，近年來已吸引許多專家及廠商投入立體顯示器的發展。傳統的偏振式投影式立體顯示器無法達到裸視效果，而裸眼式視差遮罩立體顯示器則無法應用在前投影式大尺寸顯示器上。本篇論文將結合這兩種立體顯示器的優點，提出一種全新的裸眼式前投影立體顯示器。

本論文提出的結構是利用可投出偏振光的投影機，柵狀的偏光片，以及四分之一波片和氧化銀投影幕，所製成的大尺寸前投影式立體裸眼式顯示器。而柵狀偏光片和四分之一波片的整體功能就和一般視差遮罩無異，可分離左右眼的影像分別之觀察者的左右眼中。經由模擬結果可發現，此顯示器的直視鬼影干擾可低於５％，硬體實驗結果也顯示出其直視鬼影干擾也可達到２０％以下。此種顯示器的優點包括製程容易，低鬼影干擾，可製成大尺寸(大於５０吋)，高亮度以及不需要配戴立體眼鏡。此顯示器可應用於電影院，醫學檢驗，娛樂及商業用途。

The Front Projection Type Auto-stereoscopic 3D with Retarder and Pattern Polarizer

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Abstract

In order to get more natural 3D sensation from displays, many researchers and manufacturers were attracted to invest in the development of 3D display technology in recent years. The traditional projection type polarized stereoscopic displays need to wear glasses, and the parallax barrier auto-stereoscopic display can not make in direct projection. Consequently we proposed a new kind of projection type auto-stereoscopic display combining the advantages of both projection type's polarized stereoscopic display and parallax barrier auto-stereoscopic display.

A new kind of large size directly projection type auto-stereoscopic 3D display was designed, which includes a polarization projector, parallax pattern polarizer, quarter wave plate and AgO screen. Furthermore, the function of pattern polarizer is parallax barrier, which could separate the left and right eye images for observers. The crosstalk is less than 5% in simulation for direct vision. The

experiment result shows that the crosstalk is less than 20% for direct viewing. The advantages of this structure is easy to fabricate, low crosstalk, large panel size(>50-inch), high brightness and dose not need to wear glasses, it can be used in large size movie theater screen, medical examine, entertainments, and commercial application .

誌　謝

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Chapter 1

Introduction

1.1 Preface

For the display technology industry, there have been many kinds of displays developed in the past 120 years as shown in Fig.1- 1 [1]. K. F. Braun invented the cathode ray tube (CRT) in 1897. Human eyes have three different kinds of cone cells, thus humans can sense color. Thus we have progress from black and white to colorful cathode ray tube (CRTs). After developed of CRT, Flat panel displays have become widely used because CRTs are bulky. In order to get higher image quality, many researchers have focused on high-definition televisions (HDTVs). However, the image quality is still not as good as real world images vision perceived by humans. There is no stereoscopic sensation in the above technologies which are thus classified as 2D displays.

Recently the human with technology improvement, the 3D displays have become the next generation displays, with many displays companies have began to produce 3D displays

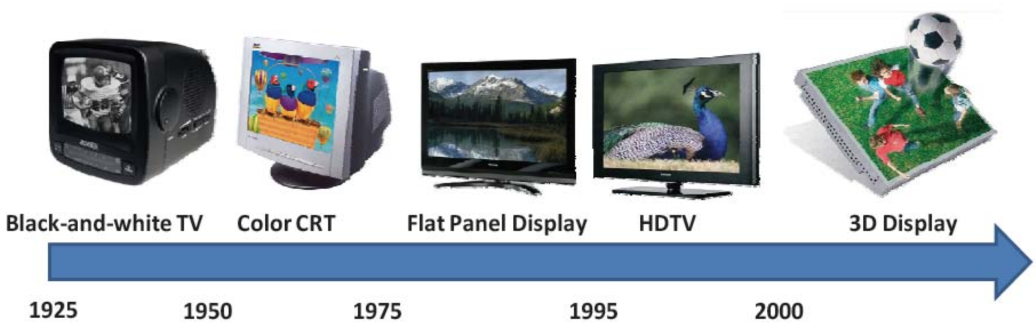


Fig.1- 1 Display improvement

1.2 Principle of 3D vision

Before the introduction of the 3D display, research result in visual science must be discussed. More than one method can allow human to perceive 3D visual. In the real world, depth cues can be divided into three kinds: monocular, binocular, and oculomotor [2].

Monocular

The monocular cue includes Interposition, Light and Shade, Texture Gradient and Aerial Perspective. Humans can feel depth information using monocular cues.

Binocular parallax

Binocular parallax is the most popular method used in 3D display, when humans see a 3D object, their left and right eyes see two different 2D images from both sides of the object, and human's brain changes these two 2D images to a 3D image, therefore human perceive the 3D vision as shown in Fig.1- 2 Binocular vision. The binocular parallax is effective and precise in recognizing the depth difference, but binocular parallax has a limitation because the objects distance must be 10m away.

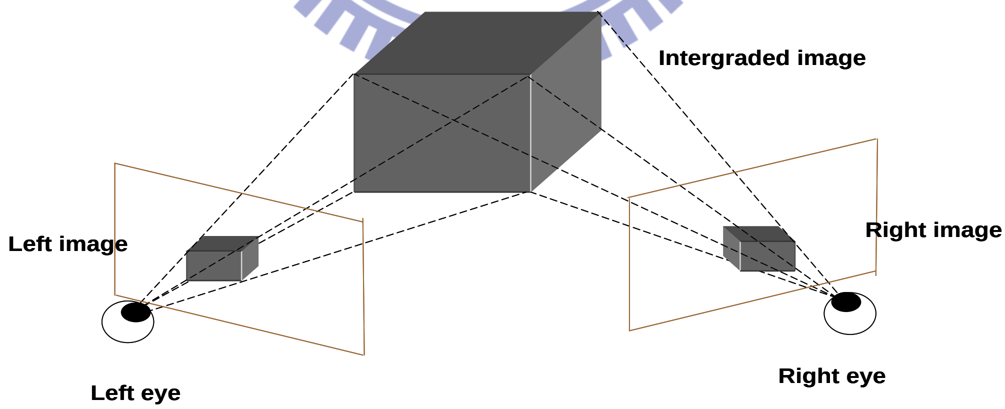


Fig.1- 2 Binocular vision

The perception of the image depended on the eye parallax as shown in Fig.1- 3, changing the distance between screens can change the perceived depth of the 3D image.

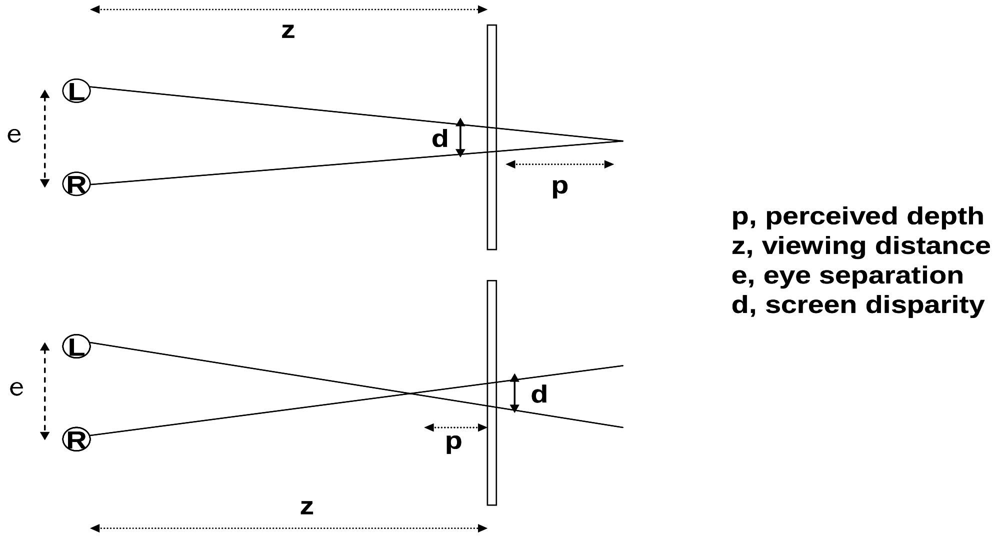


Fig.1- 3 Depth of binocular vision

Convergence

Convergence is based on the inward focus on a close object. Convergence is ineffective at long distances (~20m) as shown in Fig.1- 4.

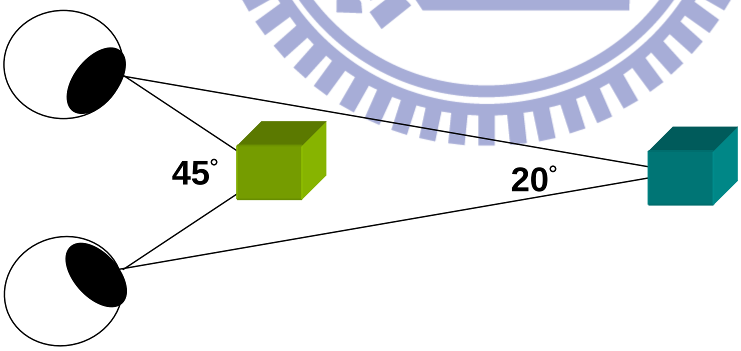


Fig.1- 4 Convergence

Accommodation

Accommodation is adjusting the shape of the lens of the eye when focusing on objects. Accommodation is effective at short distances (~3m) as shown in Fig.1- 5.

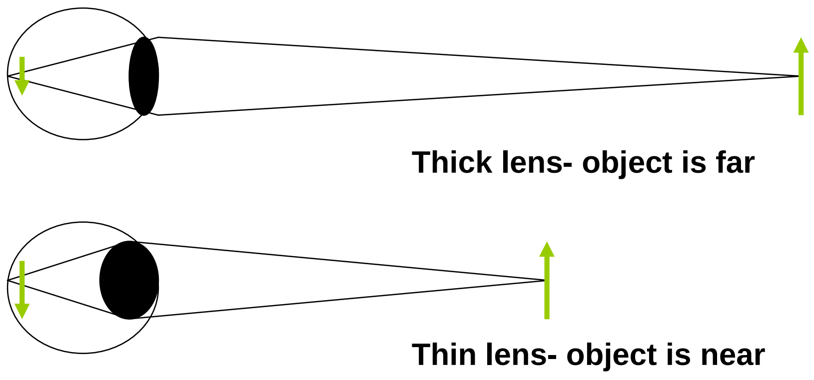


Fig.1- 5 Accommodation

Motion Parallax

Motion Parallax is when either an object in the scene or the observer's head moves. Depth cues are often provided by observers or objects movement in the visual environment.

Others

The other monocular cues are learned or based on experience and over time observers learn the physical significance of different retinal images and their relation to four cues in the real world. These include interposition, linear perspective etc.

In the real world, humans can easily perceive depth information by using the above-mentioned depth cues. In displaying visual 3D information, this is due to the fact that displays can not produce 3D information by using the occulomotor cues (convergence and accommodation), 3D displays, utilize binocular and motion parallax to produce 3D images.

1.3 Introduction to 3D display

The flat panel 3D display uses the binocular parallax principle to produce the 3D vision for humans; the display uses optics equipment to separate the left and right eye image to observer's left and right eyes, and uses the image process to combine the two different 2D image distances to control perceived depth.

3D display technology can be classified into stereoscopic and auto-stereoscopic as shown in Fig.1- 6; the stereoscopic display requires special glasses. Many stereoscopic displays have been developed [3], and humans can see this structure in the movie TV or in a computer monitor. Auto-stereoscopic systems don't require glasses; auto-stereoscopic displays were developed in recent years, there are still some issues such as viewing angle and screen size which require improvement.

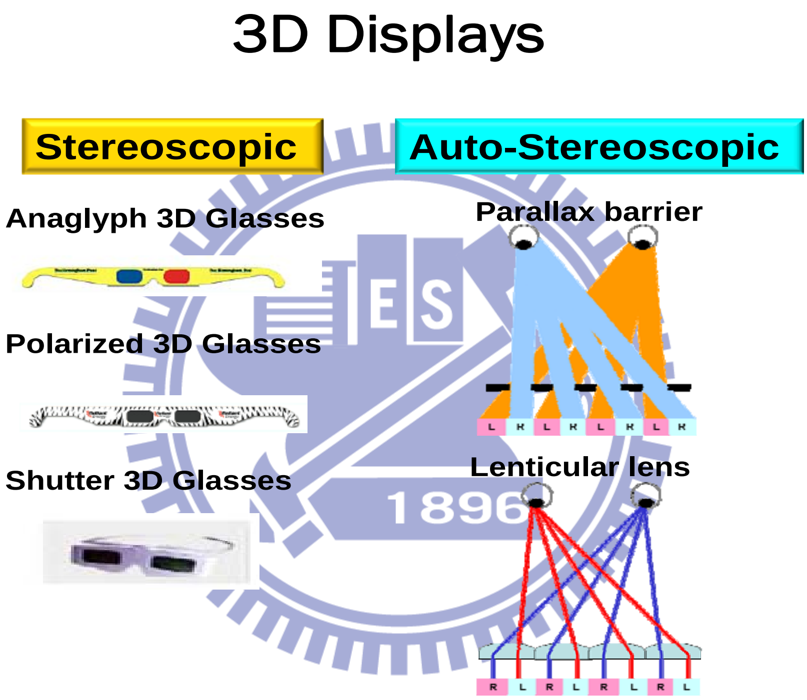


Fig.1- 6 Classify to 3D displays

1.3.1 3D display using stereoscopic system

The stereoscopic systems require observers to wear special glasses; stereoscopic displays can be classified as **anaglyph glasses**, **polarized glasses** [4] and **shutter glasses** [5]. Stereoscopic displays have been developed for more than 100 years, humans have been solved many issues in stereoscopic displays, but wearing glasses is inconvenient. Even if stereoscopic displays are inconvenient, stereoscopic displays have good image quality and fewer viewing angle limitation.

1.3.2 Auto-stereoscopic display

The auto-stereoscopic displays don't require special glasses, but auto-stereoscopic display still have many issues, such as crosstalk and viewing angle issues. The two auto-stereoscopic displays methods are **parallax barrier** [6] and **lenticular lens** [7] are shown in Fig.1- 7 (a) and (b). Both parallax barrier and lenticular lens uses optic devices to separate the left and right image to the observer's left and right eyes spatially. Auto-stereoscopic displays are the next generation display, can be applied to the Movie Theater, home TV, monitor and mobile phone.

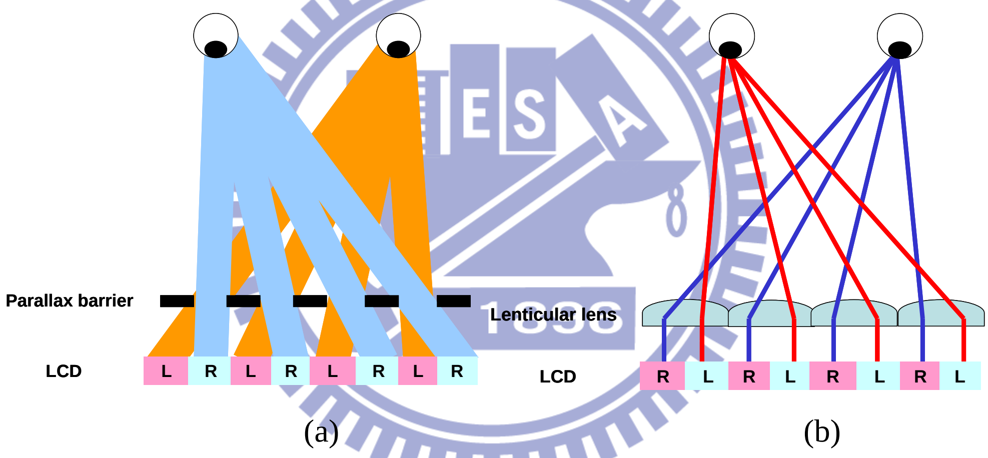


Fig.1- 7 (a) Parallax barrier (b) Lenticular lens

1.3.3 Multi-view display

When ever the auto-stereoscopic displays are used, the multi-view system [8] is required. The multi-view system can only be used in the auto-stereoscopic displays; this system can show several different images to observers at the same time in different position as shown in Fig.1- 8.

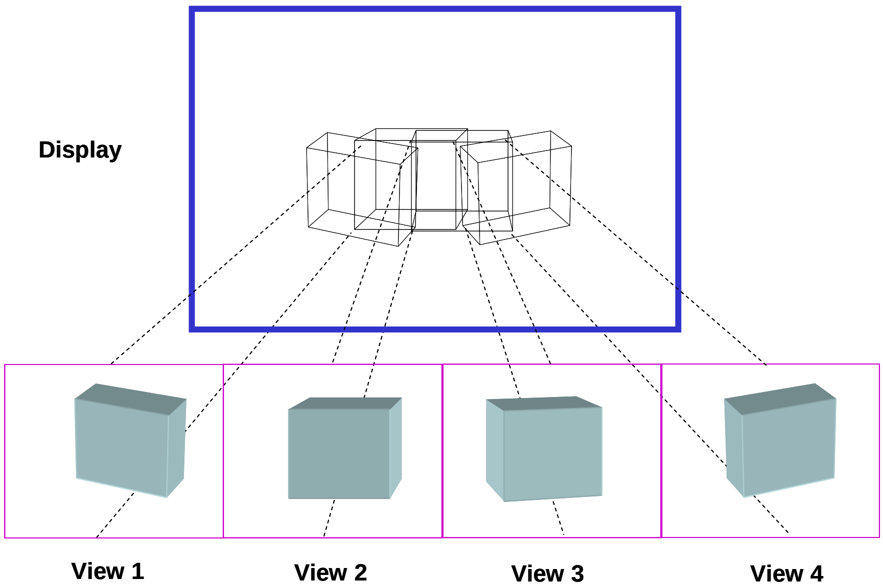


Fig.1- 8 Multi-view display

1.4 Prior Arts on projection 3D displays

The projection type 3D display has a large panel size and low cost fabrication. Projection 3D display can be classified into stereoscopic and auto-stereoscopic systems. Stereoscopic systems require glasses. Stereoscopic systems can be used in the movie theater like IMAX 3D. Projection type Auto-stereoscopic displays can be used as an optical device to separate the left and right image to the observer’s left and right eye as the ZBZX display.

IMAX 3D

The IMAX 3D system uses the projection type polarized glasses. The projection type polarized glasses display uses two projectors; one projector projects the left eye image using 45° polarization light, another projector projects the right eye image using 135° polarization light. The projectors projected the polarized light to the AgO screen, the AgO screen scatters the polarized light without changing the light polarization state, and the observers must wear glasses with the left eye polarized at

45° and right eye polarized at 135°, finally the observers see different images in each eye as shown in Fig.1- 9.

Recently many companies have proposed a circular polarizer to improve the rotated viewing angle issue such as **Master Image**. **Master Image** uses a retarder with a quarter wave plate to change the linear polarized light to circular polarized light; this method can improve the rotated viewing angle limitation issue.

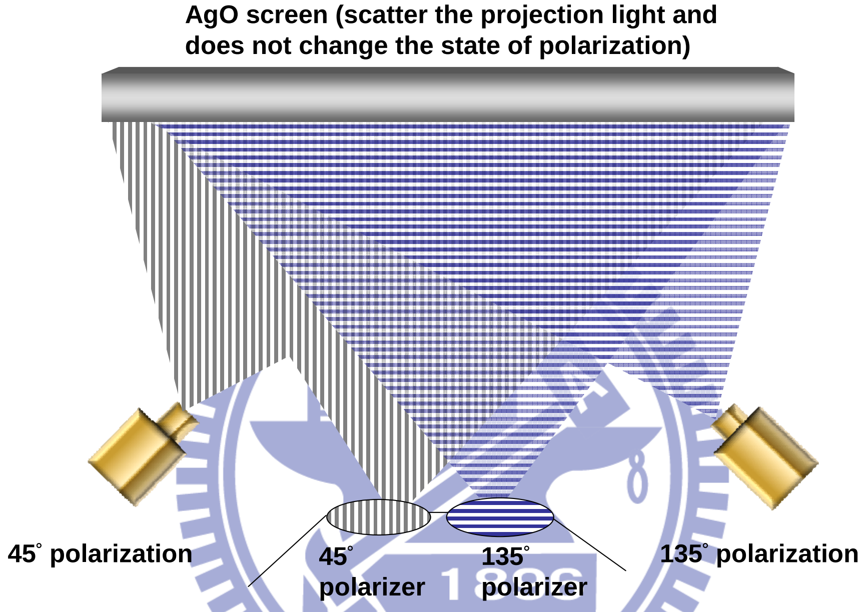


Fig.1- 9 The principle of polarization glasses

ZBZX display

The ZBZX display [9] is called the zero barriers zero crosstalk projection type auto-stereoscopic display. The ZBZX display doesn't use barrier to separate light and has low crosstalk (less than 5%). The ZBZX display uses the prism shape reflector curvature screen as shown in Fig.1- 10, when the projector projects the light on the screen. The prism shape reflector screen separates the projection light to observer's left and right eye. The prism shape reflector screen display has high light efficiency and low crosstalk. But ZBZX display has narrow viewing angle and viewing window, complex structure, and only for two observers.

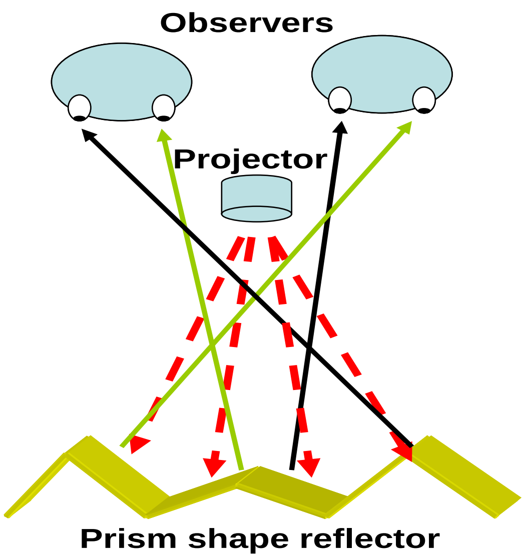


Fig.1- 10 The ZBZX display

1.5 Motivation and Objective

The projection type 3D display can make the larger size display easily for Movie Theater or exhibition display; IMAX3D is a projection type 3D display has large panel size for Movie Theater or home theater. But wearing glasses is too trouble to the humans.

The ZBZX display is an auto-stereoscopic projection type 3D display; ZBZX display doesn't require wearing glasses but the viewing angle is too narrow and difficult to fabricate.

The parallax barrier is a good method to make the 3D display. Parallax barrier display is easy to fabricate, parallax barrier display can make the multi-view systems easily and doesn't require special glasses. But the parallax barrier display can only use in flat panel display like LCD; the LCD has limitation to achieve large size, there are not technology uses the parallax barrier display in direct projection type display.

In order to make the large size auto-stereoscopic direct projection type 3D display, this thesis combines the advantages of the projection type display and parallax barrier, to make a projection type auto-stereoscopic display which is used in the Movie Theater or exhibition, large size and doesn't require wearing glasses.

1.6 Organization

This thesis is organized as follows. In **Chapter 2**, is the principle of the proposed structure. In **Chapter 3,** is the simulation about the light distribution and the crosstalk calculation In **Chapter 4**, the experiment result about the structure demo and the issues will be presented. In **Chapter 5**, the improve method of experiment. Finally, the conclusions and future works will be given in **Chapter 6**.

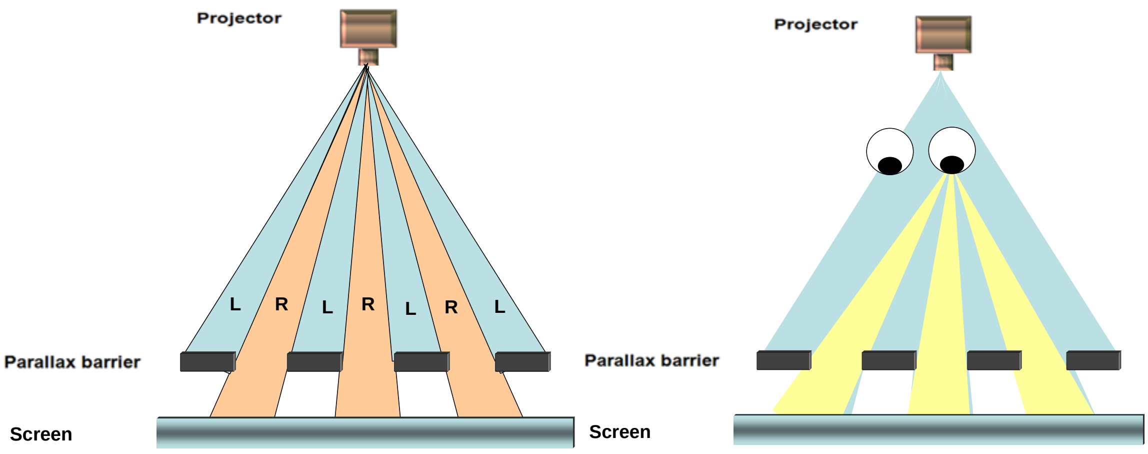
Chapter 2

The proposed structure

2.1 Traditional parallax barrier uses in projection type

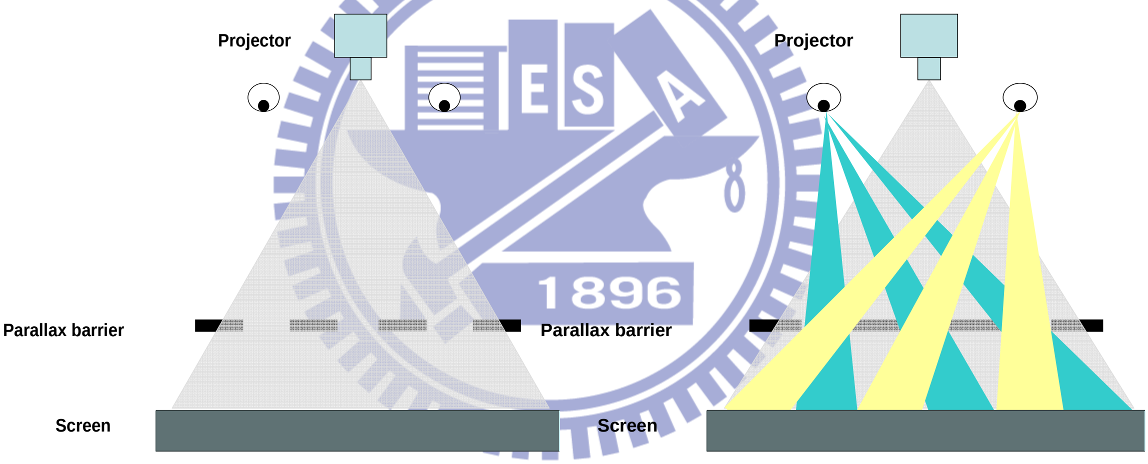
In order to make a projection type auto-stereoscopic display, the projected lights are totally projected to the screen, and the optic equipment on the screen such as parallax barrier; parallax barrier separates the reflection light from the screen to observer's left and right eye position. If we used the conventional parallax barrier in the projection type display, the parallax barrier blocked at least 50% of the projected light, and one of the eyes signal was blocked by the parallax barrier as shown in Fig.2- 1 (a). The parallax barrier destroyed the image on screen and did not separate the left and right images to correct position; observers only saw one eye image as shown in Fig.2- 1(b). Conventional projection type parallax barrier was difficult to produce the 3D image for observers.

If we wanted to receive the full 3D information, we have to make some optical device on the screen. The ideal projected light totally pass through the parallax barrier as shown in Fig.2- 2 (a), the parallax barrier only separates the reflected light on the screen as shown in Fig.2- 2 (b).



(a) (b)

Fig.2- 1 (a) Traditional barrier design uses in projection type (b) Observers see one eye image only



(a) (b)

Fig.2- 2 (a) The ideal projected light path (b) parallax barrier separates the reflected light on screen only

2.2 The proposed structure

2.2.1 Equipments- Pattern polarizer and quarter wave plate

In order to receive the information for both eyes by the projection type parallax barrier auto-stereoscopic display, we used the 45° linear polarized projector, Quarter wave plate, Pattern polarizer and AgO screen.

Polarized projector

The polarized projector is a projector which projects the linear polarized light in variable polarization direction; we used the conventional DLP projector [10]. The projected light projected from DLP projector is none polarized light. The 3LCD [11] and LCOS [12] projector did not use in this proposed structure because of the projected light from 3LCD and LCOS projector has the different polarization direction in RGB color. We placed a variable polarizer in front of the DLP projector to change the projected light to linear polarized light at fixed polarization direction.

Quarter wave plate

Quarter wave plate is an optical device made by the birefringence material [13]. The quarter wave plate is a wave retarder has fixed optic axis. If the incident light is polarized light at polarization direction 45°, when the light pass through the quarter wave plate at optic axis is 0°, after the light pass through the quarter wave plate, the transmittance linear polarized light changes to circular polarized light. If the incident light is circular polarized light, when the incident circular polarized light pass through the quarter wave plate, the circular polarized light changes to linear polarized light as shown in Fig.2- 3 and Fig.2- 4.

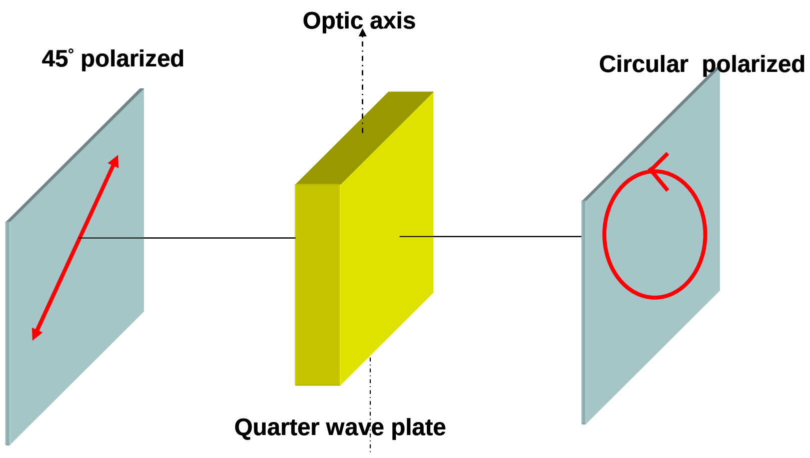


Fig.2- 3 Linear polarized light pass through the quarter wave plate

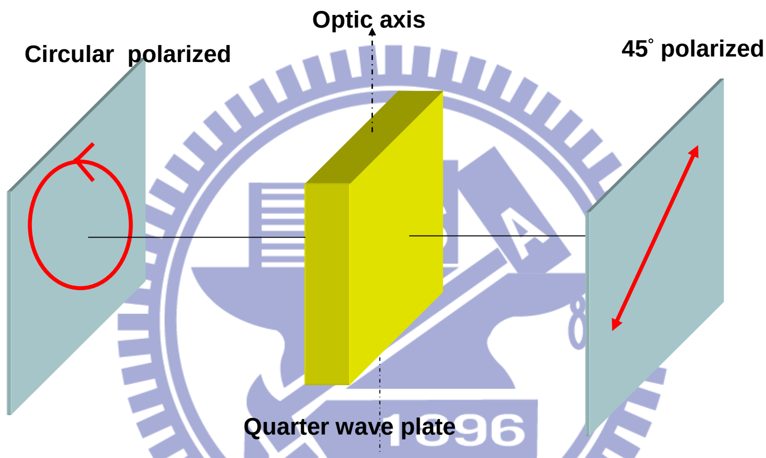


Fig.2- 4 Circular polarized light pass through the quarter wave plate

Pattern polarizer

The pattern polarizer is made by a conventional polarizer; this polarizer is cut to the strip shape in fixed length and width, the strip shape polarizer is periodicity in same gap as shown in Fig.2- 5. We placed the pattern polarizer on the top of quarter wave plate, the gap between the screen and the pattern polarizer is fixed.

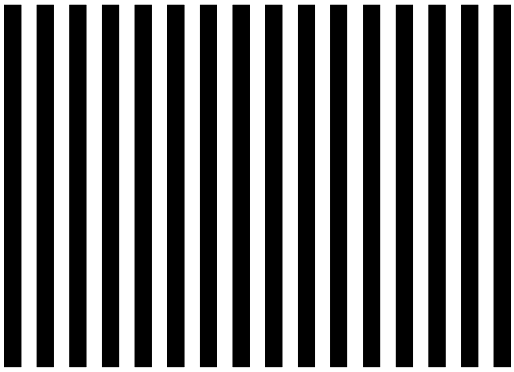


Fig.2- 5 The shape of pattern polarizer

AgO screen

The conventional projection screen destroys the polarization direction of the projected light. We used the AgO screen [14] in proposed structure. AgO screen is a special screen in the diffusion surface, the surface of the screen has the tiny AgO pellet coating as shown in Fig.2- 6. If the projected light has polarization state, we used the conventional screen did not maintain the polarization state as shown in Fig.2- 7 (a); we used the AgO screen to scatter the light without changing the projected light's polarization state as shown in Fig.2- 7(b). AgO screen is usually used in the movie theater for IMAX3D stereoscopic display.

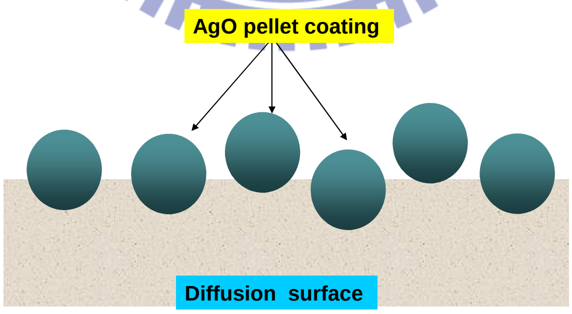
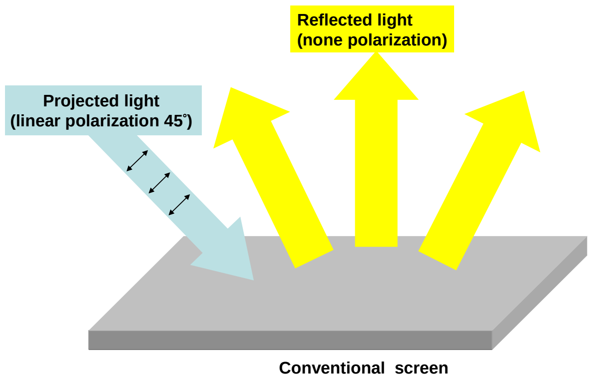
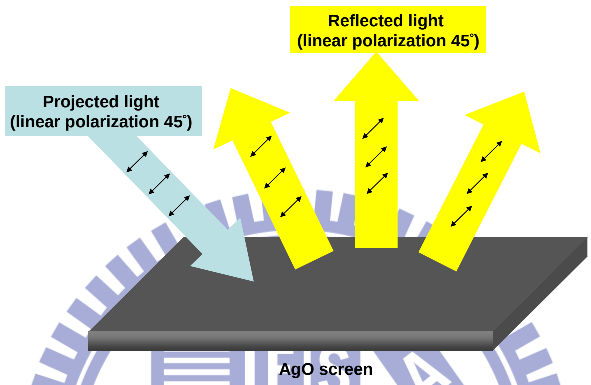


Fig.2- 6 The structure of the AgO screen



(a)



(b)

Fig.2- 7 (a) The polarized light projects on the conventional screen (b) The polarized light projects on the AgO screen

2.2.2 Proposed structure device

The proposed structure used a projector to project the image at 45° polarized. We used a pattern polarizer in 45° on the screen. We placed a quarter wave plates under the pattern polarizer, and we used an AgO screen as the projector screen to scatter the projected light and did not change the state of polarization, as shows in Fig.2- 8, the 3D vision of proposed structure as shown in Fig.2- 9.

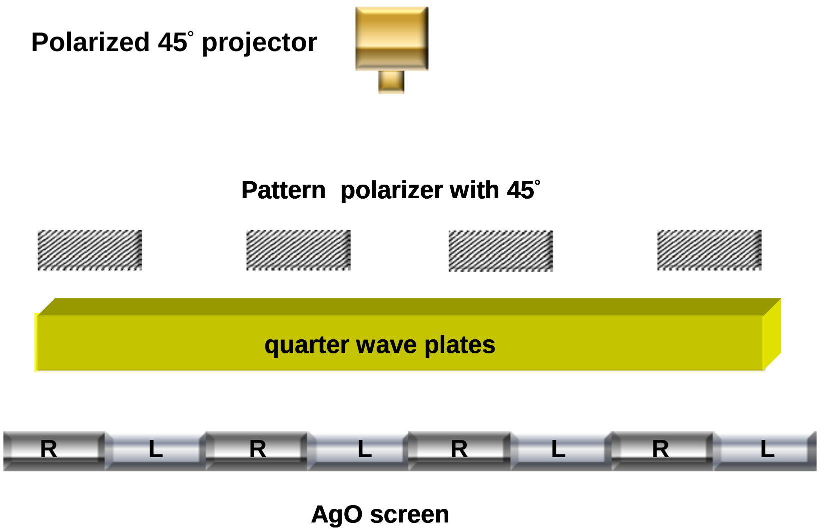


Fig.2- 8 Proposed structure design

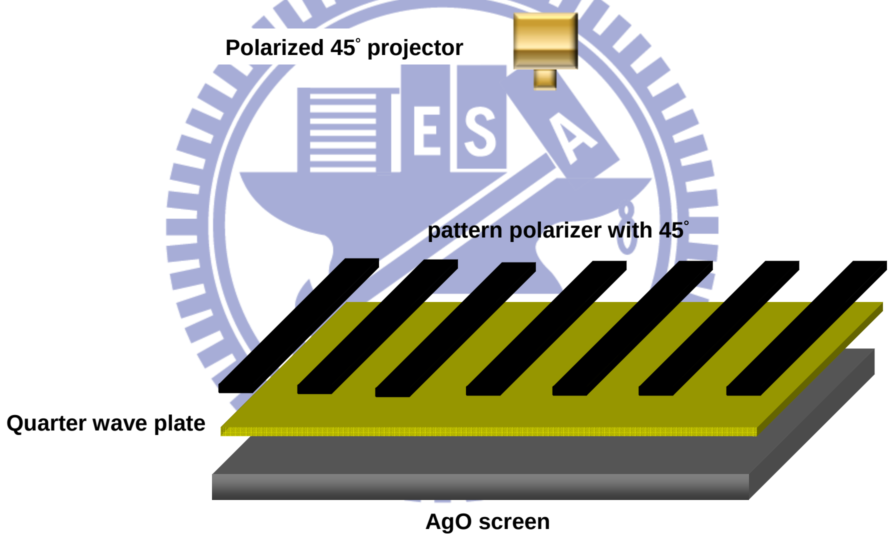


Fig.2- 9 The 3D vision of proposed structure

2.3 Principle of proposed structure

The projected light at 45° polarized totally passed through the 45° pattern polarizer. When the light passed through the quarter wave plate, linear polarized light was changed to the right hand circular polarized light and the projected light was scattered on the AgO screen as shown in Fig.2- 10. When the light was reflected through the AgO screen, the right had circular polarized light was changed to left hand circular polarized light. When the reflected light passed through the quarter wave plate again, the polarization direction changed to 135°. And the reflected light was blocked by the pattern polarizer at 45°, and other light passed through the pattern polarizer if there were not blocked by the pattern polarizer as shown in Fig.2- 11.

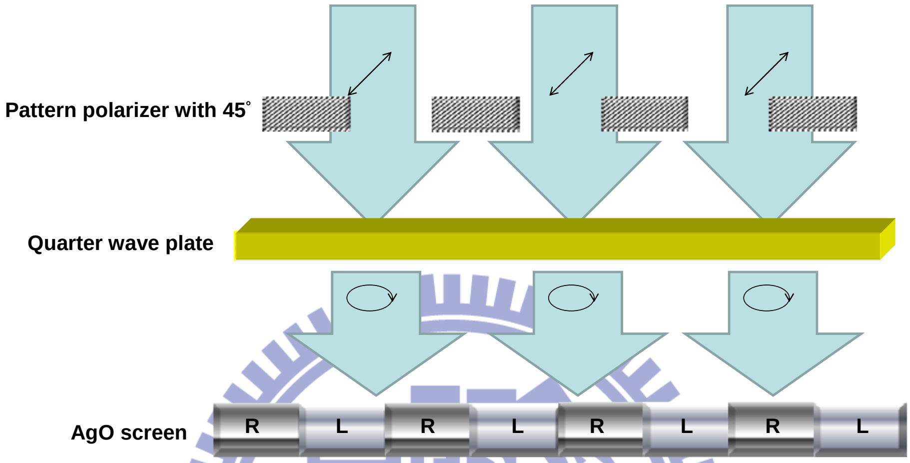


Fig.2- 10 The light path for incident light

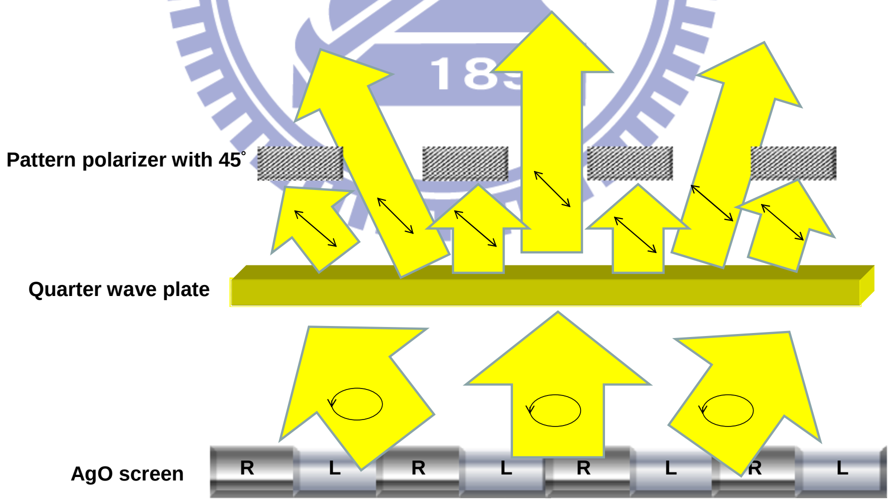


Fig.2- 11 The light path of reflected light

2.4 Light path of the proposed structure

This structure required the projected light totally passing through the pattern polarizer and prorogating to the screen, and the pattern polarizer separated the reflected light only to the identical position. The totally light path shows in Fig.2- 12. We compared the proposed structure and the traditional projection type parallax barrier as shown in Fig.2- 13. The proposed structure did not block the projected light and separated the reflected light on the screen only. This proposed structure was similar to the parallax barrier display; the entire parallax barrier characteristic is able to use in this proposed structure.

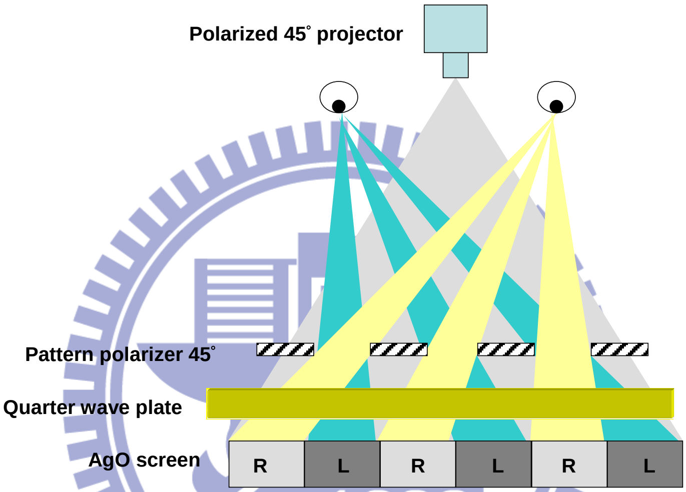
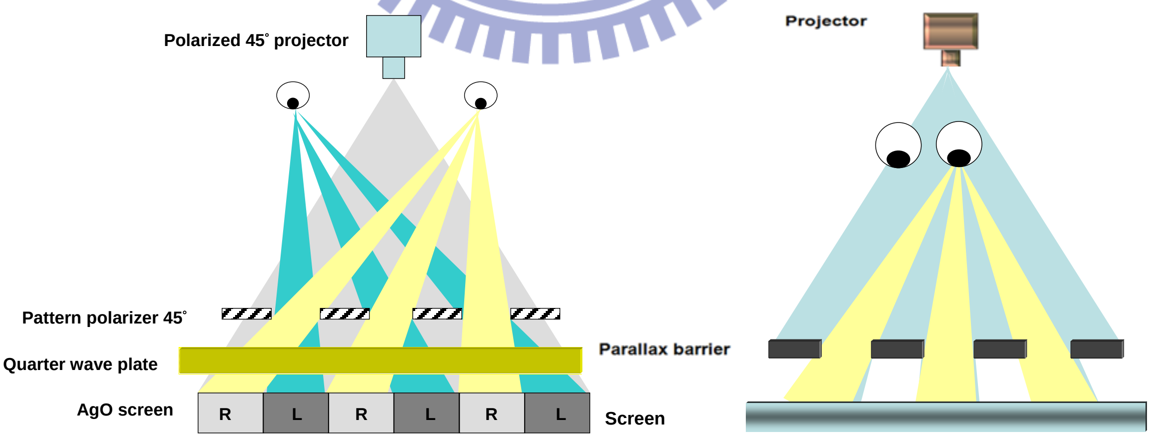


Fig.2- 12 Total light path of proposed structure



(a) (b)

Fig.2- 13 Comparison between the (a) Proposed structure (b) Conventional projection type parallax barriers

2.5 Proposed structure design formula

There is a pattern polarizer designing as shown in Fig.2- 14 [15]. If the pixel pitch, viewing distance have been know, the human eyes distance 6.5mm, and the gap distance between barrier and pixel are calculated by the barrier design formula as shown in Fig.2- 14.

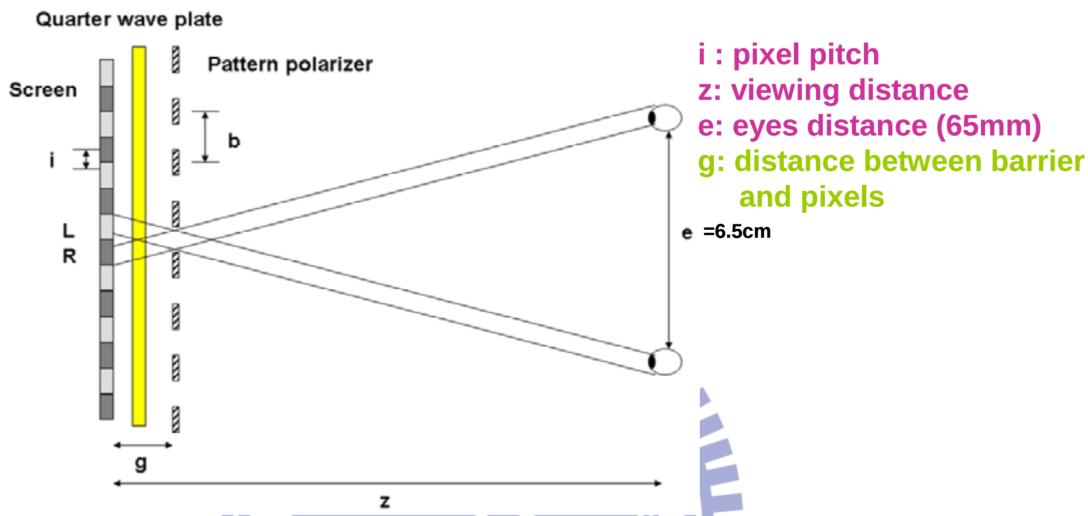


Fig.2- 14 Parallax barrier design structure

The pixels and barrier are arranged so the centre of each pair of left and right view pixels is visible at the centre of the viewing windows. The geometry defining the design of the parallax barrier pitch, b, can then be determined from considering similar triangles in Fig.2- 14

$$\frac{b}{z-g}=\frac{2i}{z} \tag{1}$$

The formula (1) can be rearranged to give:

$$b=2i\left(\frac{z-g}{z}\right) \tag{2}$$

The result (2) is that the barrier pitch for a two viewing window display is just less than twice the pixel pitch on the display. This small difference between the pixels and the barrier pitch accounts for the variation in viewing angle between the eyes and the pixels across the display and is often referred to as viewpoint correction.

Viewing distance, z, for the best quality viewing windows is another design factor and again from similar triangles in Fig.2- 14 we can deduce a geometric relationship for this.

$$\frac{i}{g} = \frac{e}{z-g} \tag{3}$$

The result (3) can be rearranged to give:

$$z = g\left(\frac{e+i}{i}\right) \tag{4}$$

We used this design formula to fabricate the proposed structure model, we designed the simulation model to find the optimized pattern polarizer size and made the model to demo this proposed structure.

2.6 Multi-view display design formula

Changing the barrier aperture size in pattern polarizer can make the multi-view display as shown in Fig.2- 15. If parameters of this multi-view display are known, we can use the design formula (5), (6) and (7) to design the multi-view display.

$$a = \frac{e \cdot n \cdot i}{e + n \cdot i} \tag{5}$$

$$b = a(n-1) \tag{6}$$

$$g = \frac{i \cdot z}{e + i} \tag{7}$$

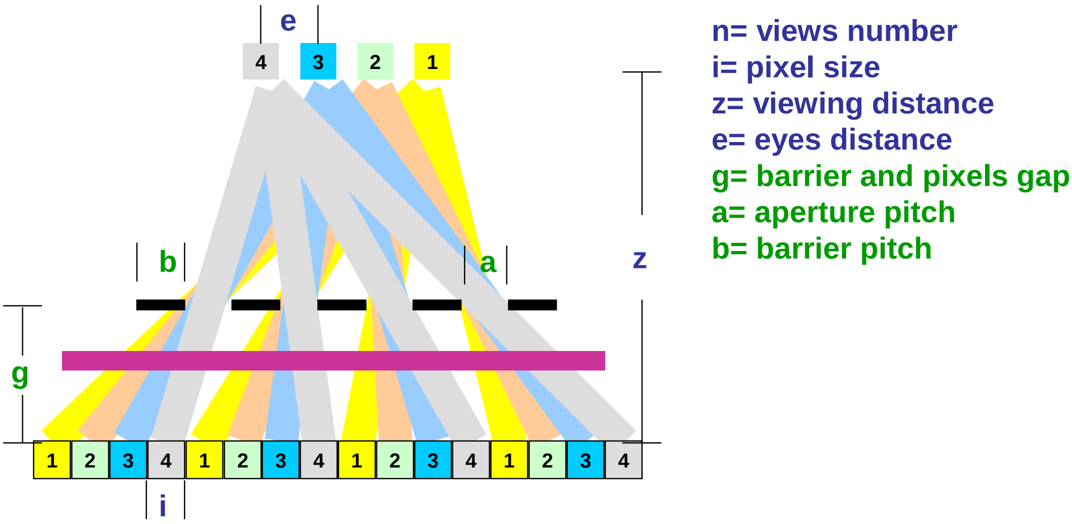


Fig.2- 15 The multi-view display design structure

Chapter 3

Simulation Results

After designing the proposed structure, we had to simulate this proposed structure; we used lighttools to make the model and simulated it in this chapter. We find the light distribution for proposed structure about the left and right eye image intensity compared to normalized intensity and the viewing angle, and the crosstalk calculation results. Finally we changed the parameter of the pattern polarizer to find the optimized results and simulated the multi-view model.

3.1 Simulation model setup

We used the crosstalk value to determine the 3D image quality of the 3D displays, the crosstalk [16] formula shows in Fig.3- 1. We assumed the screen size was 50*40cm, the pixel pitch was 2mm, the pattern polarizer pitch was 4mm, aperture size was 2mm, projected distance was 4m, the pattern polarizer and screen gap was 4cm as shown in Fig.3- 2.

Crosstalk definition: $$\textit{Crosstalk} = \left[\frac{\text{right image (ghost image)}}{\text{left} + \text{right image}} \right] \times 100\,\%$$

Fig.3- 1 The crosstalk definition

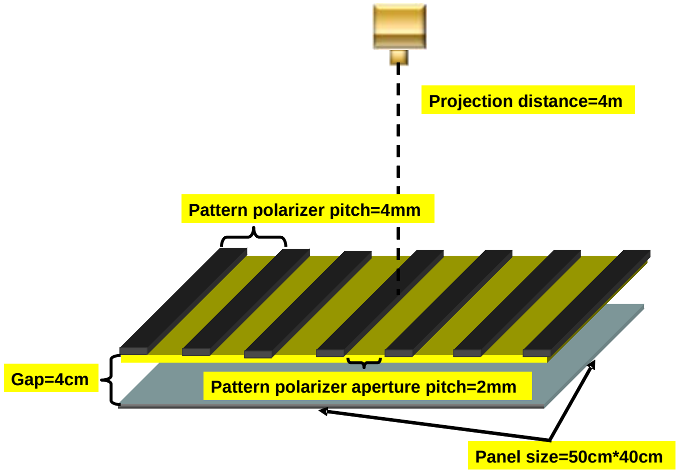


Fig.3- 2 The simulation model of the proposed structure

3.2 Simulation in light distribution

The simulation results of the light distribution in proposed model as shown in Fig.3- 3. Fig.3- 3 shows the light distribution in normalized intensity compared with the viewing angle. The viewing angle was from 0° to 30°. The proposed structure separated the left and right eye image to fixed position clearly. The average crosstalk was less than 5% for each eye in normal direction (0°). But the crosstalk increased to 20% in larger viewing angle (30°). The brightness decreased 70% than the normal direction (0°). This simulation results showed the 3D effect in this proposed structure was good if observers stand in the correct position in direct viewing.

But in this proposed model, the viewing window of the light distribution was not good enough. If observers moved their head, observers did not see the clearly 3D image, the viewing window was too narrow in this model, and the crosstalk value in larger viewing angle was large.

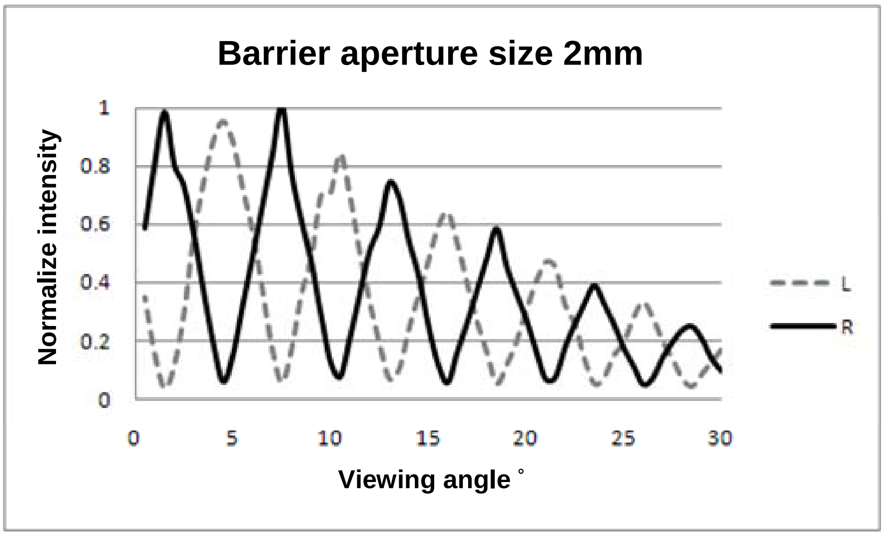
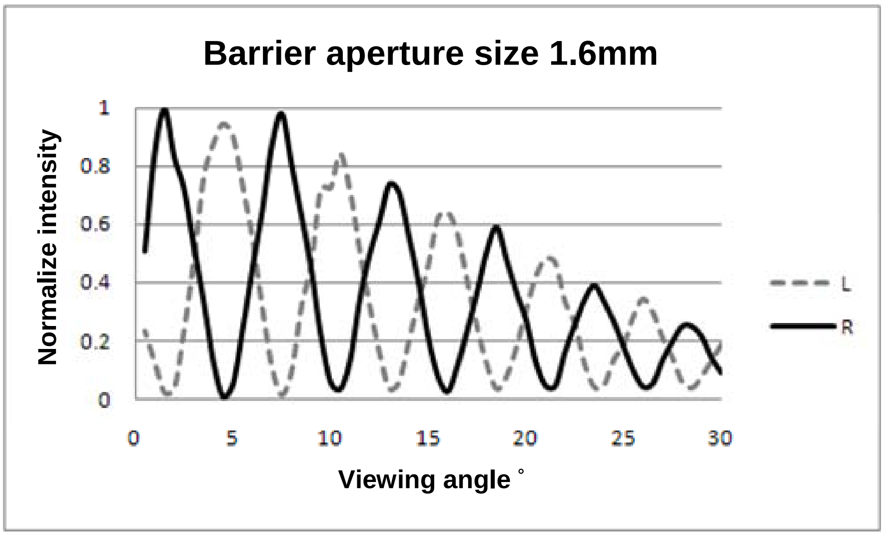


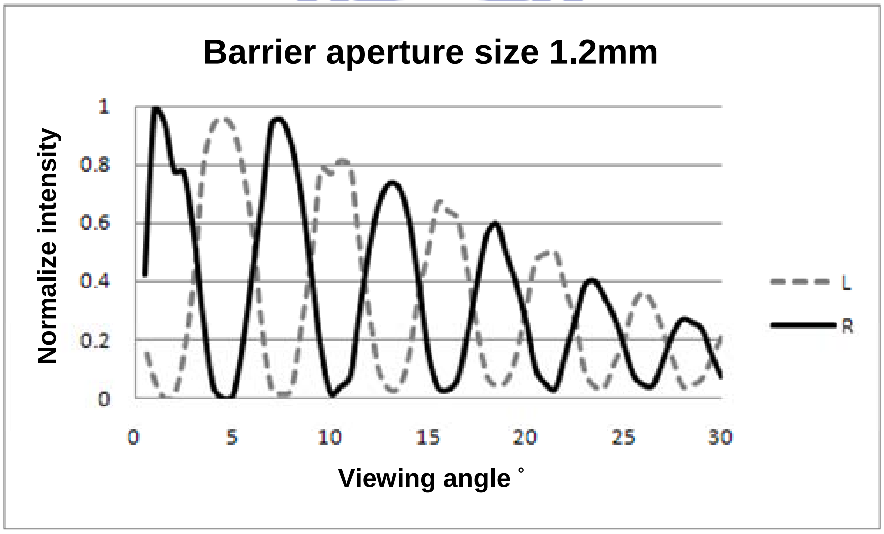
Fig.3- 3 Light distributions in 0°~30° for proposed model

3.3 Improved in viewing window and crosstalk issues – open aperture optimization

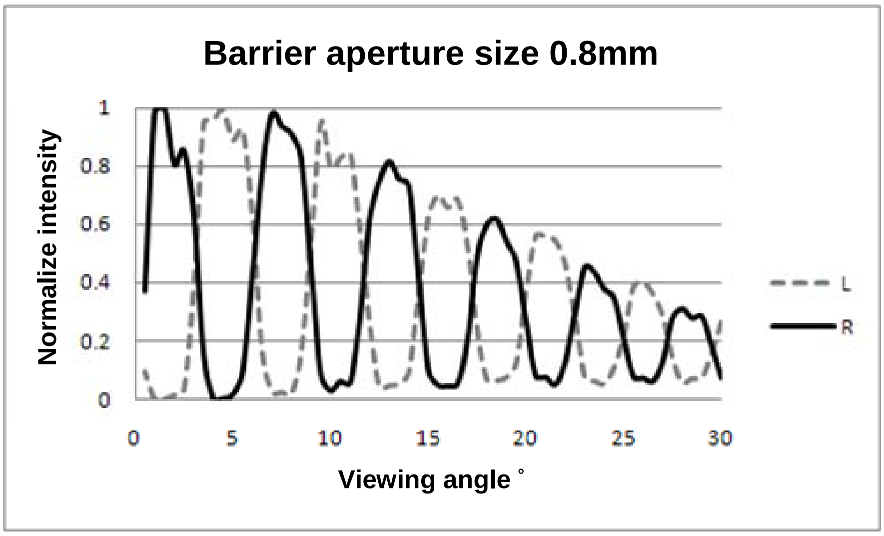
From the previews simulation results, the crosstalk was increased when the viewing angle increased, and the narrow viewing window issues. The proposed structure is used in the movie theater, if the crosstalk increases in larger viewing angle, the observers set in the wide viewing angle did not see the high quality 3D image, and the narrow viewing window issues limited the observer's viewing position. The larger viewing angle crosstalk issues and viewing window issues should be improved. The improved method was varied the pattern polarizer aperture size; the following simulation models varied the aperture size from 1.6mm to 0.4mm.


Barrier aperture size 1.6mm
Normalize intensity
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
25
30
Viewing angle °
L
R

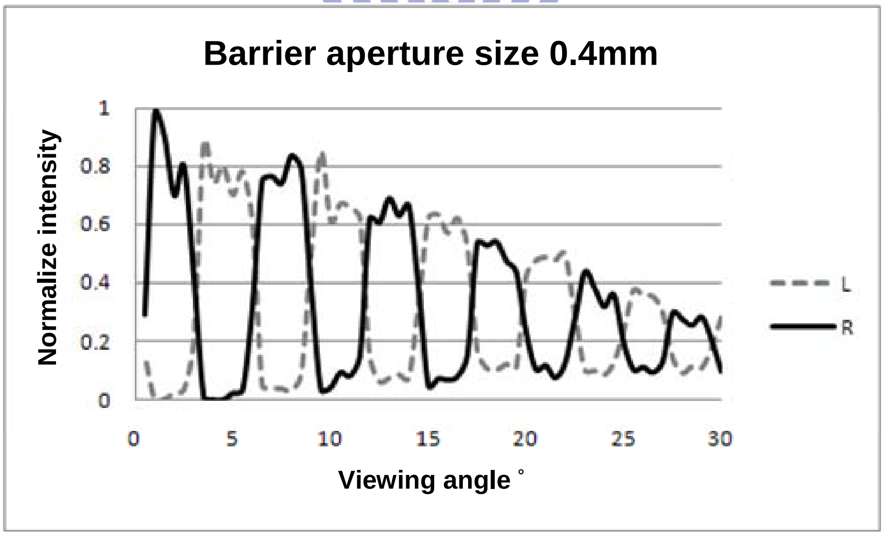
(a)


Barrier aperture size 1.2mm
Normalize intensity
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
25
30
Viewing angle °
L
R

(b)



(c)



(d)

Fig.3- 4 Pattern polarizer aperture size (a) 1.6mm (b) 1.2mm (c) 0.8mm (d) 0.4mm

We changed the aperture size from 1.6mm to 0.4mm, the simulation results as shown in Fig.3- 4 (a) to (d). The larger viewing angle (30°) crosstalk value in pattern polarizer aperture size 2mm is 20%. The crosstalk value variation in pattern polarizer aperture size from 2mm to 0.4mm is shown in Fig.3- 5.

Changing the pattern polarizer aperture size from 2mm to 0.4mm, the average crosstalk decreased from 20% to 12% in aperture size 1.2mm, but the crosstalk increased to 25% by changing the pattern polarizer aperture size from 1mm to 0.4mm as shown in Fig.3- 5. Because of the total brightness of the light was decreased through the narrow aperture size. The optimized pattern polarizer aperture size is 1.2mm had the smallest crosstalk value 12%.

When we changed the pattern polarizer aperture size, the light distribution of left and right eye image became more clearly. The viewing window of the light distribution by changing pattern polarizer from aperture size 1.6mm to 0.4mm became wide. The light distribution was changed form triangle wave distribution to square wave distribution in narrow pattern polarizer aperture size as shown in Fig.3- 4 (a) to (d). Observers can see the better 3D image when we changed the pattern polarizer aperture size from 2mm to 1.2mm.

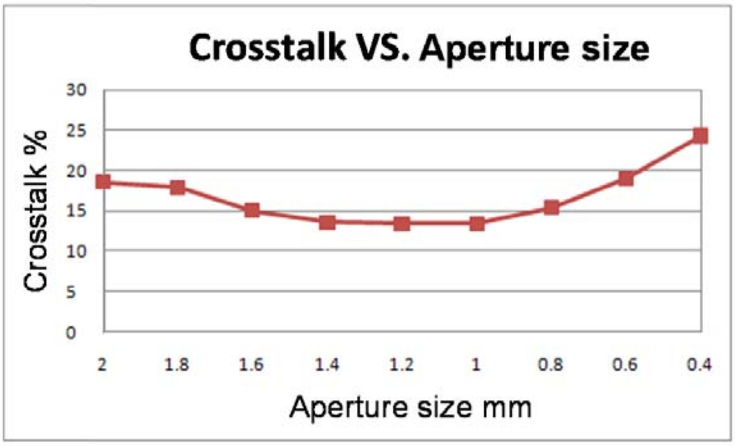


Fig.3- 5 Crosstalk compare with aperture size

The light efficiency by changing pattern polarizer aperture size 2mm to 0.4mm decreased from 100% to 20% as shown in Fig.3- 6, if we want to obtain the low crosstalk and wide viewing window, we decreased the pattern polarizer aperture size, but when we decreased the aperture size the light efficiency was decreased too, this is a trade-off between the crosstalk and light efficiency.

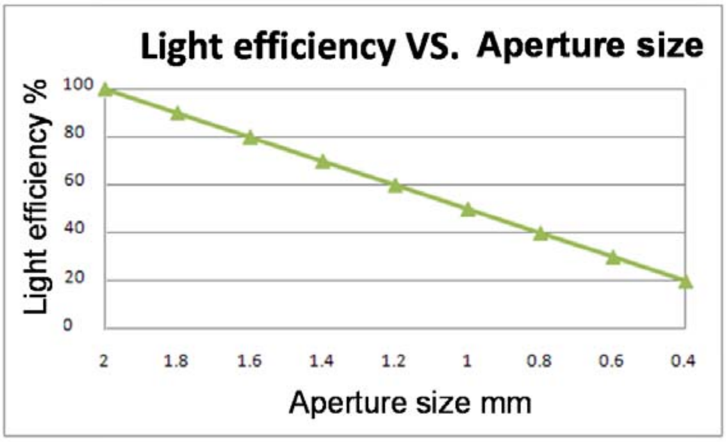


Fig.3- 6 The light distribution compare with viewing angle

3.4 The multi-view system

The most powerful advantage for this system is the multi-view system; the proposed structure can make the multi-view system easily. We changed the pattern polarizer aperture size and changed the pattern polarizer and AgO screen gap can make the multi-view system [17]. The 4 views multi-view display model as shown in Fig.3- 7.

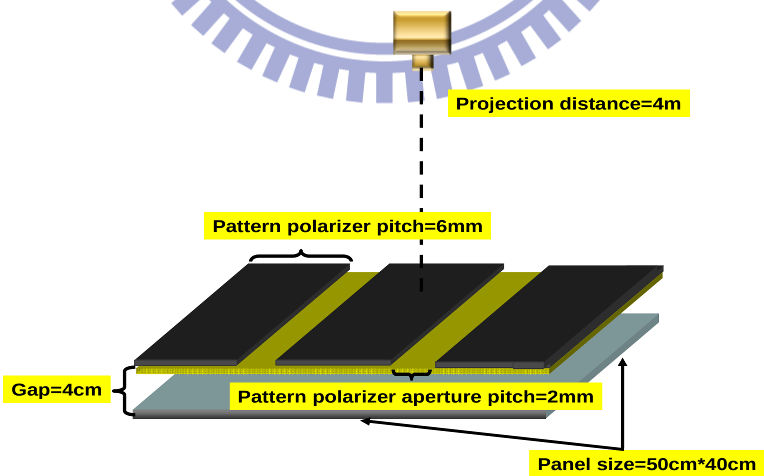


Fig.3- 7 The 4 views multi-view display model

The light distribution of the each view about the normalized light intensity compared to the viewing angle is shown in Fig.3- 8. This multi-view display separated the each view image to the each viewing position. The average crosstalk of each view was less than 10% in normal direction. But the viewing window of the light distribution was not good enough, we optimized the viewing window issue, the previews discussion showed the optimize pattern polarizer pitch was 1.2mm. The aperture size 1.2mm multi-view display simulation results as shown in Fig.3- 9, the average crosstalk in direct viewing was less than 5%, and viewing window for light distribution was better than the aperture size 2mm model.

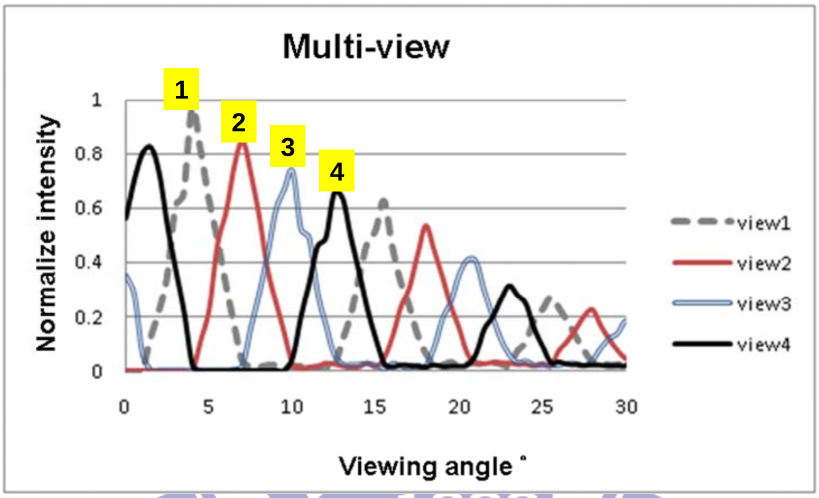


Fig.3- 8 The light distribution for 4 views multi-view system.

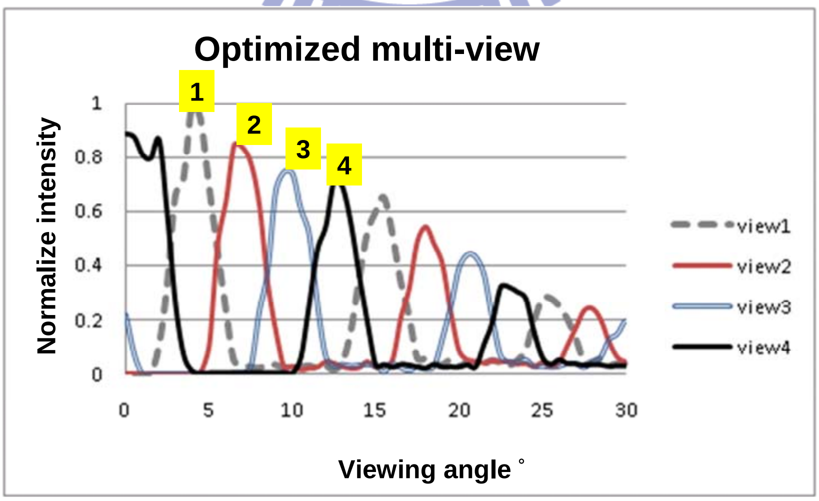


Fig.3- 9 The light distribution optimized multi-view system (4-views).

3.5 Summary

The simulation crosstalk for the proposed structure by lighttools was 5% in normal direction (0°), the crosstalk increased in the wide viewing angle (30°), we changed the pattern polarizer aperture size to decrease the crosstalk. The optimized aperture pitch is 1.2mm; the crosstalk in wide viewing angle (30°) is 15%.

Changing the barrier aperture size decreased the crosstalk value, but the brightness is decreased too, this is a trade-off between the light efficiency and crosstalk.

The proposed structure can make the multi-view system easily, the simulation result in 4-views multi-view display crosstalk is 10%, and the optimized average crosstalk value is 5%.

Chapter 4

Experimental Results

After simulation, the proposed structure separated the left and right image to the fixed position, and observers stood in the correct position saw a 3D image. The demo structure of the experiment required a linear polarized projector, a pattern polarizer, a quarter wave plate, and an AgO screen. The experimental results showed a light distribution compared to the normalized intensity and viewing angle. Finally the experimental issues are discussed.

4.1 Experimental equipment

The experimental setup is shown in Fig.4- 1. We used a linear polarized projector, a pattern polarizer, a quarter wave plate and an AgO screen.

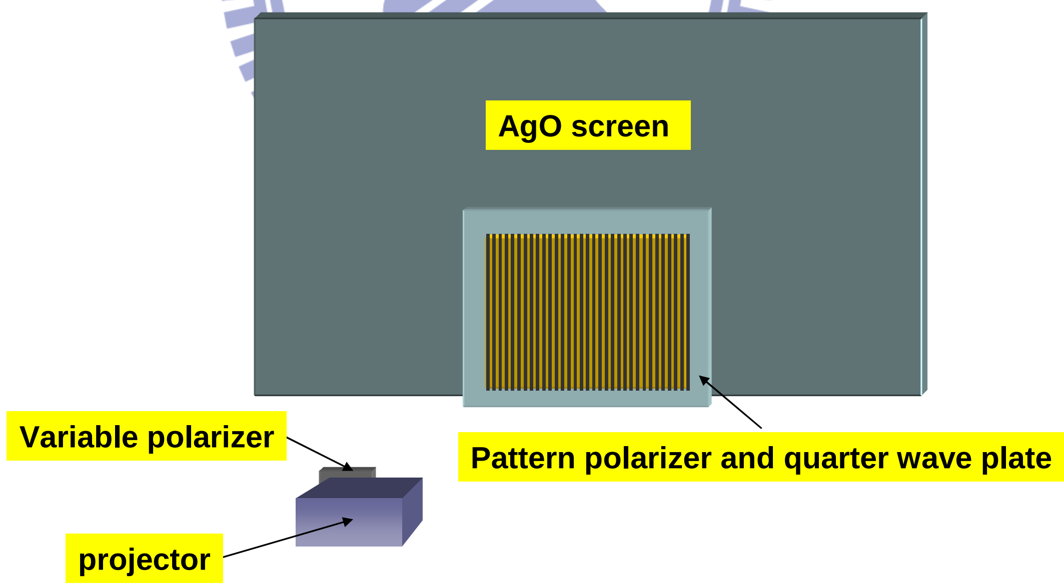


Fig.4- 1 The experimental setup

Linear polarized projector

A DLP projector at XGA (1024*768) resolution, we placed a variable polarizer at

45° in front of the projector output lens as shown in Fig.4- 2.

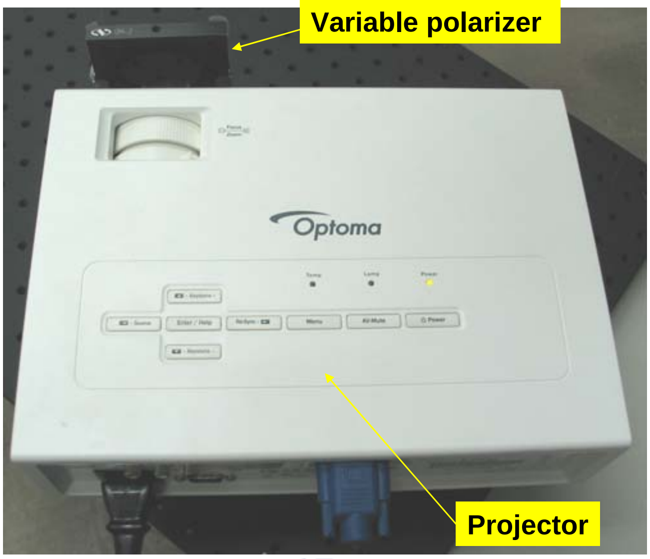
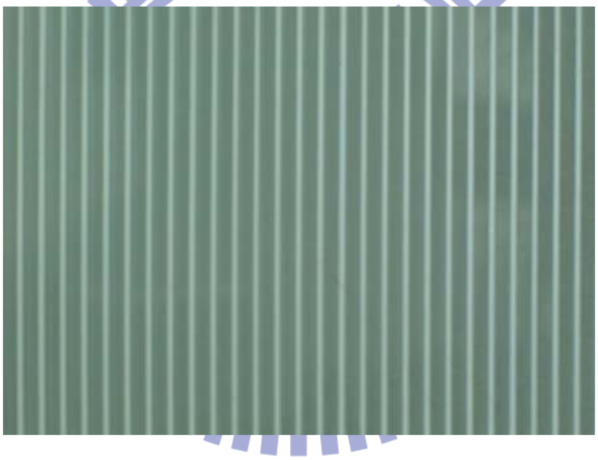


Fig.4- 2 The XGA projector and a variable polarizer in front of output lens

Pattern polarizer and quarter wave plate

The quarter wave plate was made from optimax. Making the same pitch pattern polarizer was difficult. We used CO_2 laser cutting to cut the polarizer with a precise pitch and aperture size, Fig.4- 3 shows the pattern polarizer made by the CO_2 laser cutting, the size is 50cm*40cm, the pattern polarizer pitch is 2mm, and aperture size is 2mm.

(a)



(b)

Fig.4- 3 (a) Pattern polarizer for 40*50cm (b) Pattern polarizer

AgO screen

We used an AgO screen in 100 inch Full HD (1920*1200) resolution, the AgO screen scattered projected light without changing the polarization state as shown in Fig.4- 4.

Fig.4- 4 AgO screen and pattern polarizer

4.2 Experimental method

The experiment setup is shown in Fig.4- 6, the projection distance was 400cm, because of the projection pixel size was 2mm, and the detected distance was 250cm. In this experiment, we used the SR-UL1R detector [18] to measure the light intensity at different wavelengths; the SR-UL1R is shown in Fig.4- 5. We rotated the detector around in a half circle with a radius of 250cm. We detected from 0° to 30° and recorded the light intensity as shown in Fig.4- 7. We projected the parallax left image for odd white line and right image for even black line on the screen, the line width was equal to one pixel size as shown in Fig.4- 8. We changed the white and black light and measured the light intensity of left eye and right eye signals.

Fig.4- 5 SR-UL1R detector

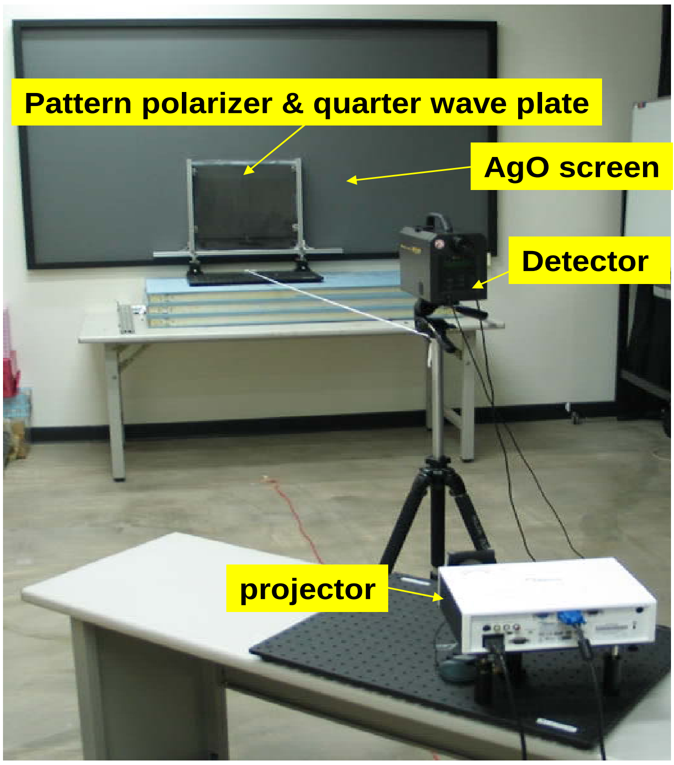


Fig.4- 6 Experimental setup

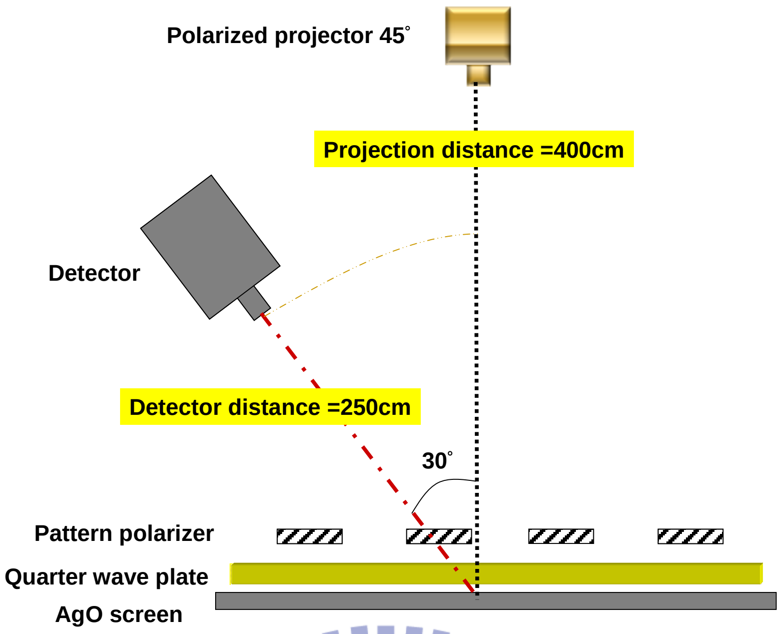


Fig.4- 7 Experimental set up parameters

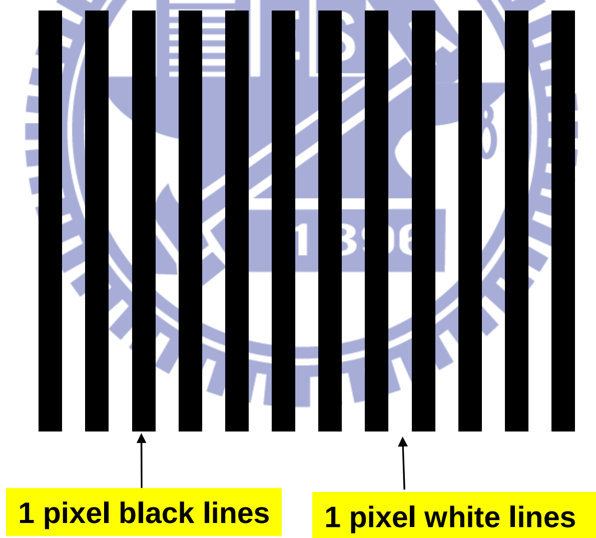


Fig.4- 8 Projected measurement image

4.3 Experimental results

After recording light intensity, the normalized intensity was compared to the viewing angle from 0° to 30° as shown in Fig.4- 9. In viewing angles 15° to 30°, the pattern polarizer did not separate the left and right eye image correctly. Brightness decreased more than 60% when the viewing angle was larger than 15°. The experimental data from 15° to 30° was too rough to analyze, so we only analyzed the experiment data from viewing angle 0° to 15°. The normalized intensity was compared to the viewing angle from 0° to 15° as shown in Fig.4- 10, and the crosstalk in the normal direction (0°) was 45%.

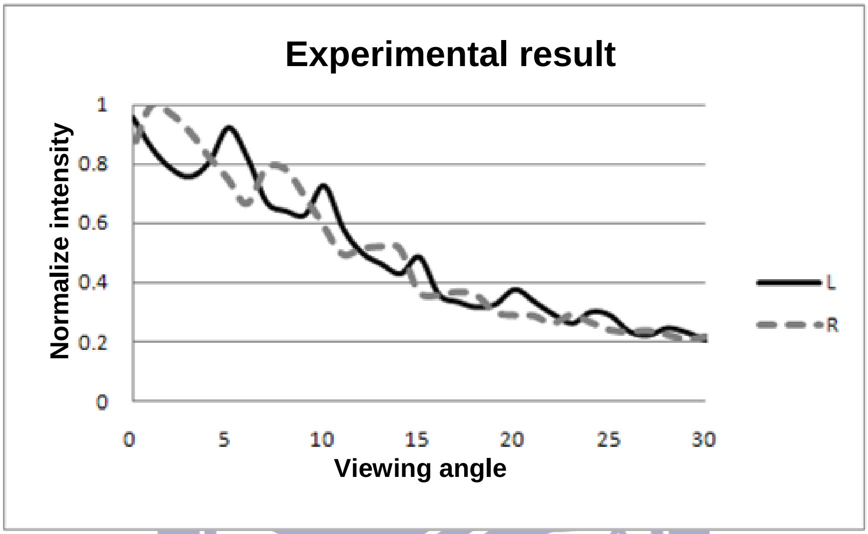


Fig.4- 9 The light distribution from viewing angle 0° to 30°

Fig.4- 10 The light distribution from viewing angle 0° to 15°

4.4 Discussion

Unfortunately crosstalk value of 45% was much larger than the previews simulation results. This phenomenon was caused by some issues we unable find by using the simulation software. The most important issue was the reflection issue from the pattern polarizer. The pattern polarizer was PVC material [19], this material reflected the projected light from the projector. Some projected light was reflected on the pattern polarizer as shown in Fig.4- 11. We call this image which was reflected on the pattern polarizer as “reflected light”. Reflected light is caused crosstalk and destroyed image quality, so observers did not want to see the reflected image. Other light passed through the pattern polarizer and quarter wave plate which was reflected at the AgO screen as shown in Fig.4- 11. We called this light reflected on the AgO screen as “image light”; this image light was seen by observers.

If observers saw a high quality 3D image, observers had to see the image light reflected on AgO screen but not the reflected light on pattern polarizer. In the next chapter, improved methods will be given.

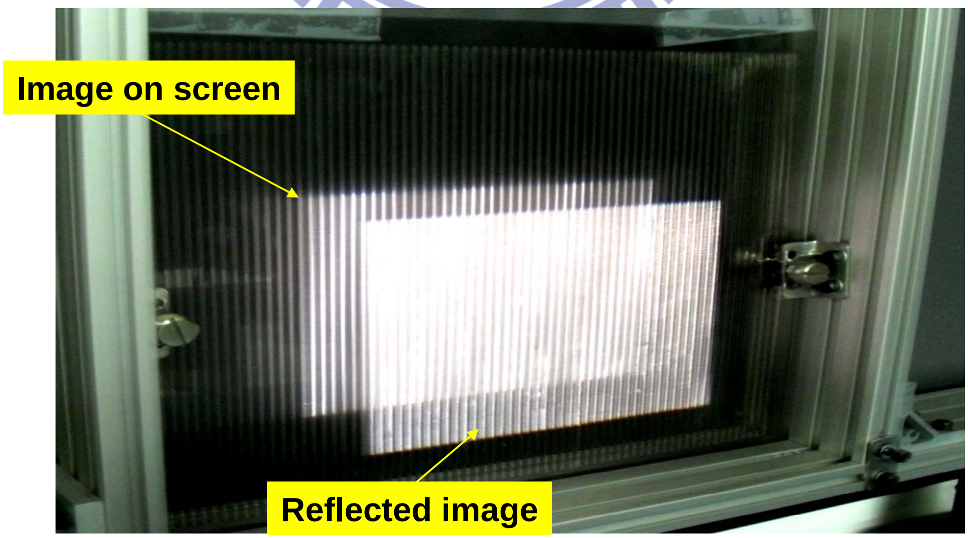


Fig.4- 11 The reflection issue of the pattern polarizer

Chapter 5

Improvement for the Crosstalk Issues

This chapter suggested some improved methods to decrease the reflected light issue. In step one; we placed an adjustment polarizer to improve the reflection issue of the pattern polarizer. In step two, we changed the pattern polarizer aperture size to reduce the crosstalk. In step three, we used the DCR (digital crosstalk reduce) method to reduce the light leakage issue of the pattern polarizer. After improvement, light distribution and crosstalk was measured. We compared the simulation results and the experimental results and discussed the issues of the crosstalk. Finally some image demo pictures are shown.

5.1 Step one: Improved in reflected light issue

Reflected light from the pattern polarizer was difficult to reduce, and reflected light destroyed the image quality which was reflected on the AgO screen.

The improved method placed a polarizer in front of observers; we called this polarizer "the adjustment polarizer" as shown in Fig.5- 1. The adjustment polarizer did not block the projector, and the polarization direction was perpendicular to the projector light's polarization direction. In adjustment polarizer direction at 135° blocked the 45° polarized projected light.

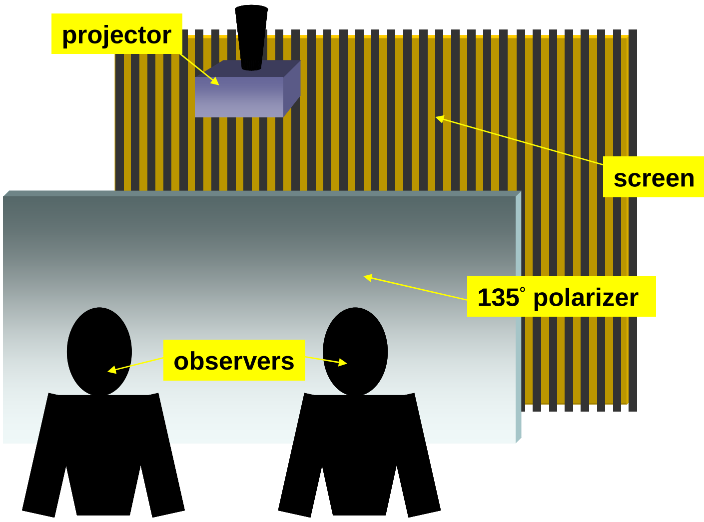


Fig.5- 1 The improved method (placed an adjusted polarizer in front of observers)

5.1.1 Principles of the improved method

The light propagated to the pattern polarizer at 45°. The pattern polarizer's surface reflected this light without changing the polarization state at 45°. The light did not pass through the quarter wave plate. We placed an adjustment polarizer in front of observers to block the reflected light at 45°, as shown in Fig.5- 2. The image light passed through the quarter wave plate and reflected on the AgO screen which changed the polarization state from 45° to 135°; the 135° image light completely passed through the adjustment polarizer at 135° as shown in Fig.5- 2. Finally observers saw the image light reflected on the AgO screen, and did not see the reflected light reflected on the pattern polarizer.

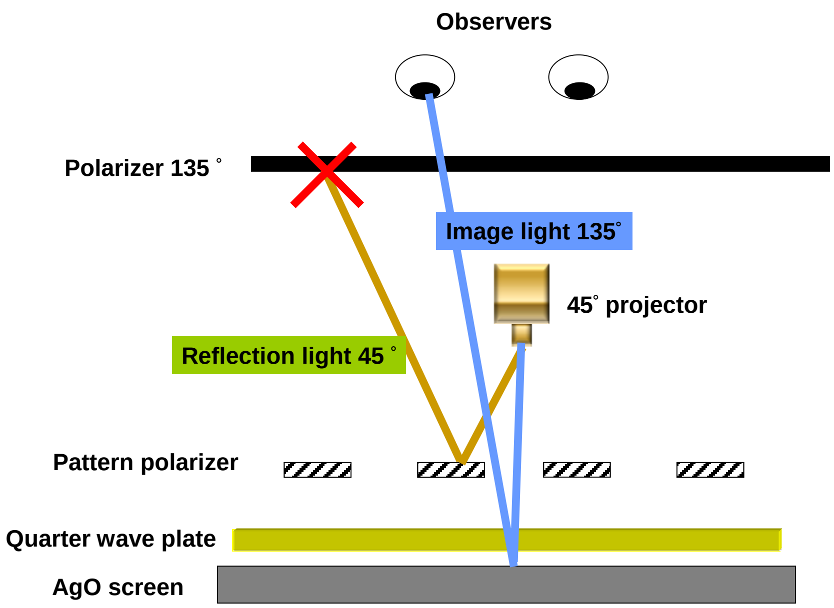
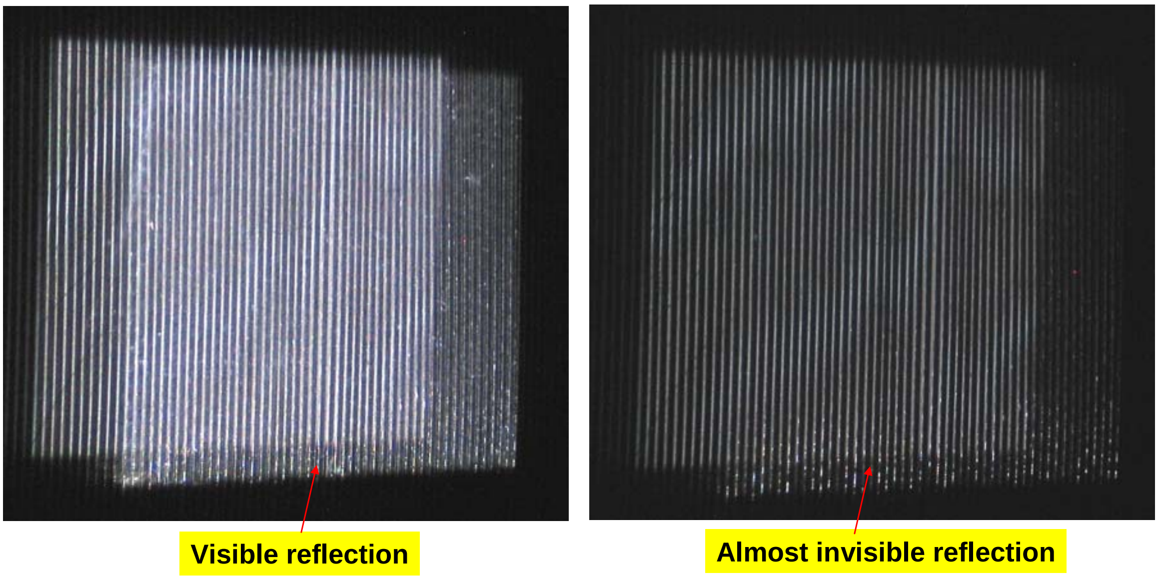


Fig.5- 2 The principle of improved method

5.1.2 Experimental Results of improved method

Fig.5- 3(a) shows the reflected image before the improvement and Fig.5- 3(b) shows the improved result. The reflected light before improvement was much brighter than the image light. After improvement, the reflection light decreased through the adjustment polarizer; therefore image light on AgO screen was brighter than reflected light on pattern polarizer. We used a detector to measure the reflected light decreased through the adjusting polarizer by 80%, the image light is also decreased through the adjustment polarizer by 20%.



(a) (b)

Fig.5- 3 (a) The reflection light before improvement (b) The reflection light after improvement

5.1.3 Light Distribution Measurement

Light distribution after improved by placing an adjustment polarizer in front of the detector as shown in Fig.5- 4, we compared the result of normalized intensity and the viewing angle in left and right eye images, this improvement result separated the left and right eye image to fixed position more clearly than the original experimental results. Crosstalk was decreased to 30% after improving. The image quality was much better than original experimental results. The comparison between the original experimental result and the improvement result as shown in Fig.5- 1. The crosstalk value of 30% was still much larger than the simulation result. The previews simulation results showed the optimized pattern polarizer aperture size was 1.2mm; we used this pattern polarizer aperture size to optimize the experimental result.

Fig.5- 4 The improved light distribution by placing the adjustment polarizer in front of the detector

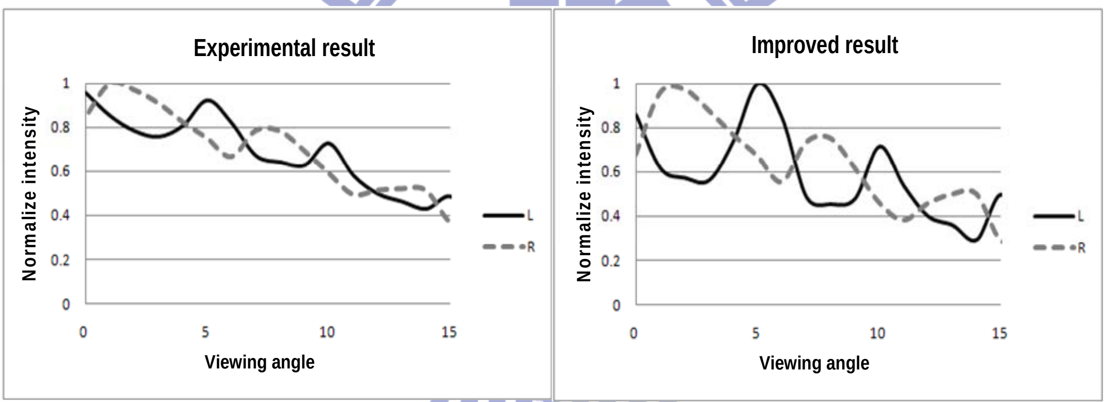


Fig.5- 5 The comparison before and after placing the adjustment polarizer in front of the detector

5.2 Step two: Open aperture optimized

After placing an adjustment polarizer in front of the detector, crosstalk was still larger than the simulation result. In Chapter 3 the simulation results showed the optimized simulation pattern polarizer aperture size was 1.2mm. We changed the pattern polarizer aperture size to 1.2mm. The experimental result is shown in Fig.5- 6.

The optimized experimental result separated the left and right eye image to fixed position clearly. The crosstalk was 20% in normal direction. And the crosstalk was much better than the original experimental result, as shown in Fig.5- 7. But the crosstalk was higher than the simulation result as shown in Fig.5- 8; there were still some issues to be discussed.

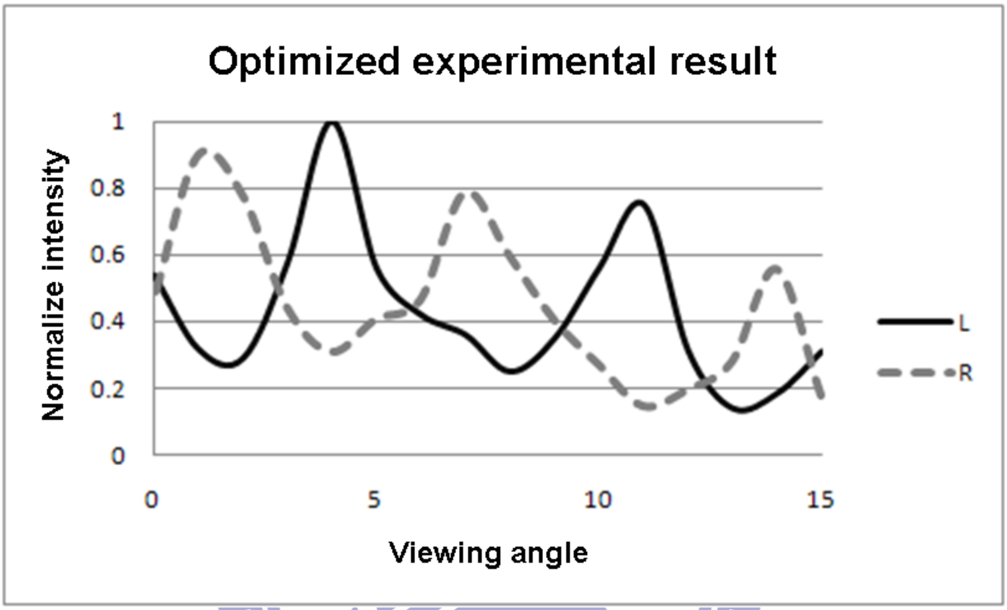


Fig.5- 6 The aperture size of 1.2mm experimental results

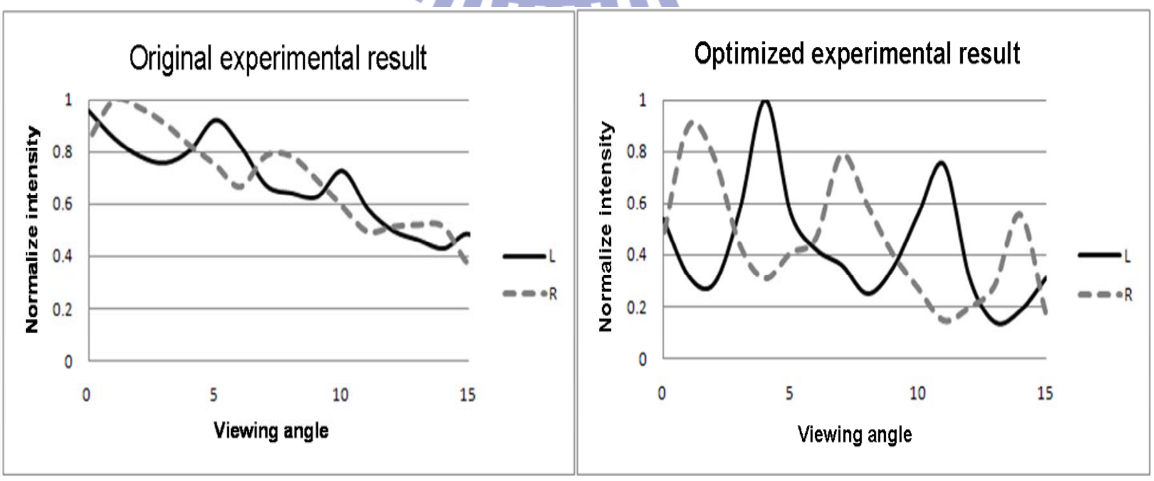


Fig.5- 7 A comparison between the original experimental results (pattern polarizer aperture size 2mm) and the optimized results (pattern polarizer aperture size 1.2mm)

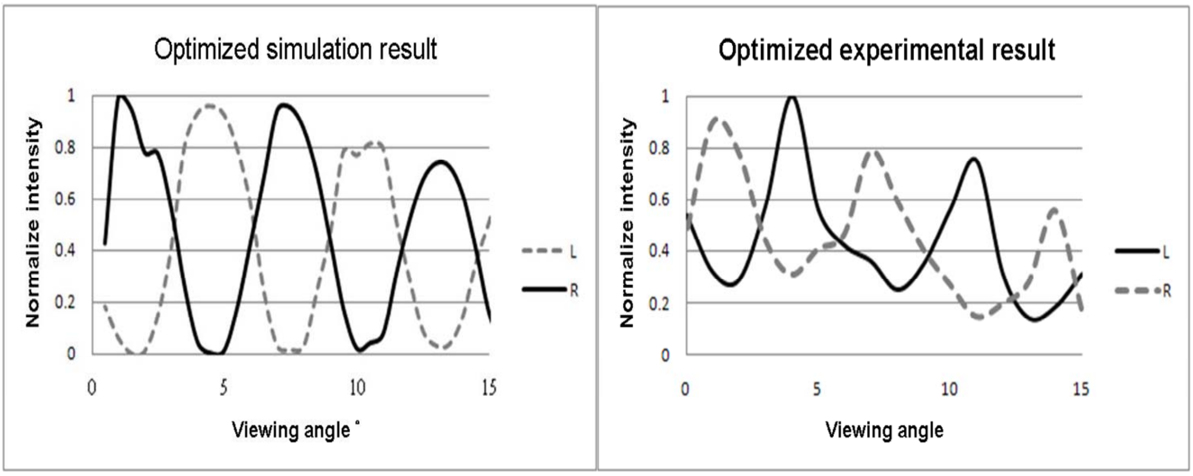


Fig.5- 8 A comparison between the optimized simulation result and the optimized experimental result (pattern polarizer aperture size 1.2mm)

5.3 The crosstalk issues

The pattern polarizer and quarter wave plate light leakage

The pattern polarizer and quarter wave plate unable to block all light, because the pattern polarize and quarter wave plate is not the ideal parallax barrier. The pattern polarizer and quarter wave plate had different light leakages at different wavelengths. Pattern polarizer light leakage is depended on the wavelengths as shown in Fig.5- 9. The pattern polarizer and quarter wave plate had different light leakages at different wavelengths, even the lowest light leakage at a wavelength of 550nm was 15%. So the different wavelengths caused different crosstalk as shown in Fig.5- 10. The best crosstalk value was 20% at a wavelength of 490nm, but at a wavelength of 700nm, the crosstalk was 50%. The pattern polarizer light leakage caused larger crosstalk than the ideal parallax barrier.

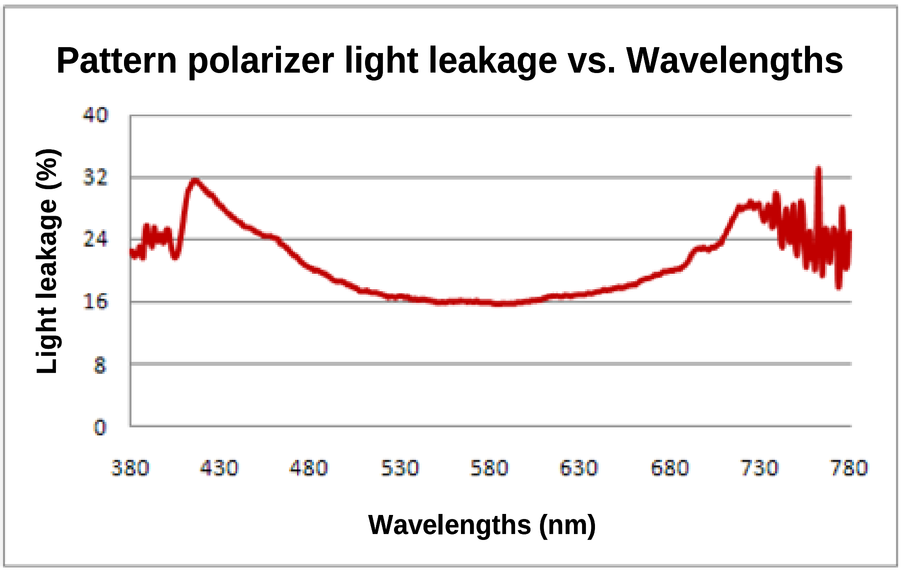


Fig.5- 9 Pattern polarizer light leakage compared to wavelengths

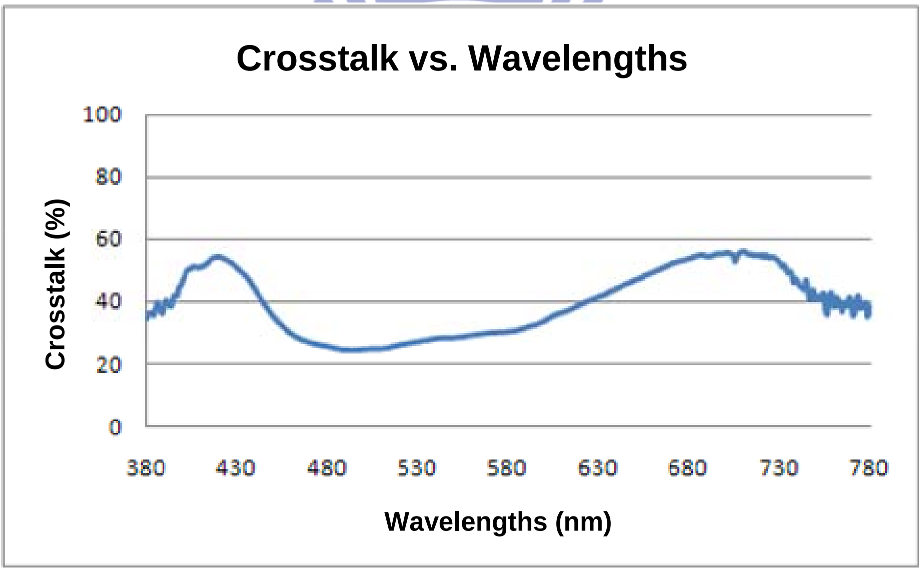


Fig.5- 10 The crosstalk compared to the wavelengths

The AgO screen light leakage

AgO screen did not reflect all the polarized light without changing the polarization state; some none polarized light was transmitted to the pattern polarizer and adjustment polarizer. The light leakage was 10% of the AgO screens, which caused crosstalk.

Projector issues

The DLP projector had a contrast ratio issue and alignment issue as shown in Fig.5- 11, the black line pixel was not dark enough than the white light pixel, and the line pixel width was no equal to the white line pixel width. The ideal input projected image is shown in Fig.5- 12; the black line pixels width should be equal to the white line pixel width. In this experiment, the black line pixel width was 1.5mm, and white line pixel width was 2.5mm.

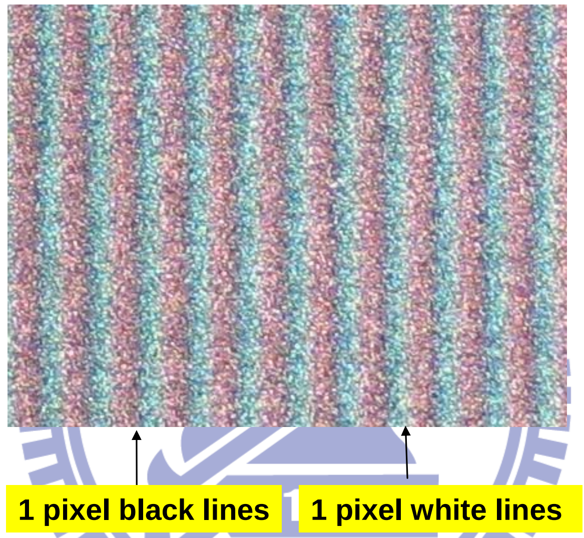


Fig.5- 11 The projected image on screen

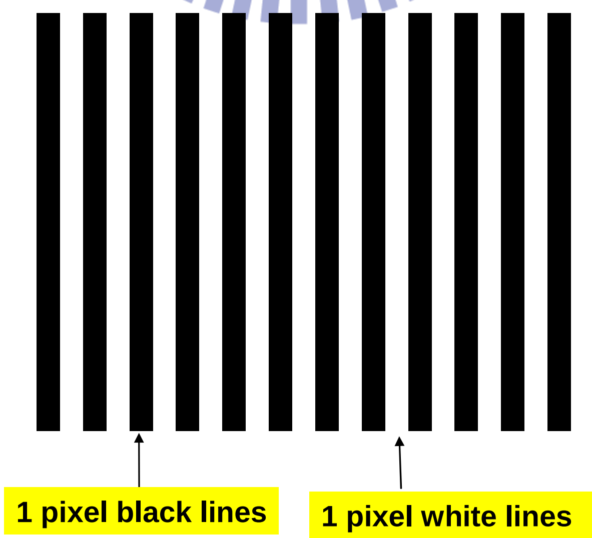


Fig.5- 12 The ideal input projected image

The simulation results of the alignment issues is shown in Fig.5- 13, the black line pixel width was 1.5mm and white line pixel width was 2.5mm. The light distribution about the left and right eye image is similar to the optimized experimental results as shown in Fig.5- 19, the crosstalk was 15%; the alignment issue caused the crosstalk in the experiment. To achieve the best experimental results, we should use the precise DLP projector; align the pixel and the pattern polarizer accurately.

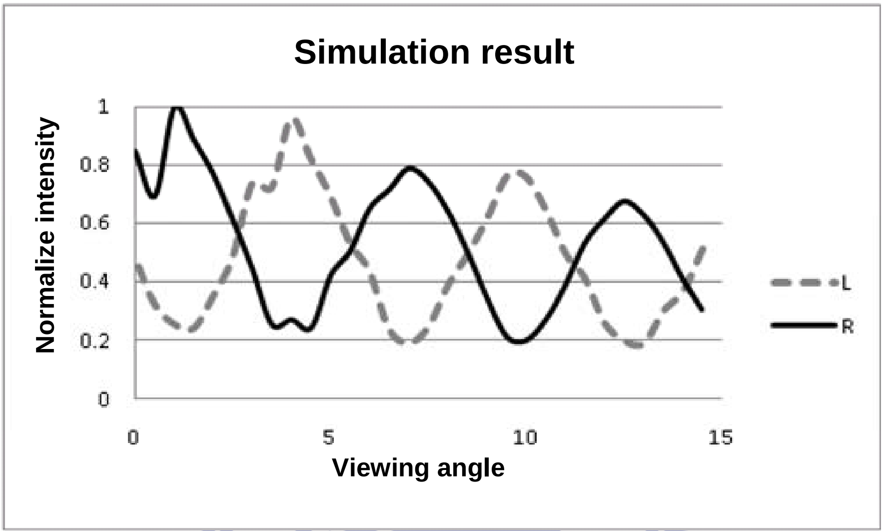


Fig.5- 13 The simulation results of the alignment issue

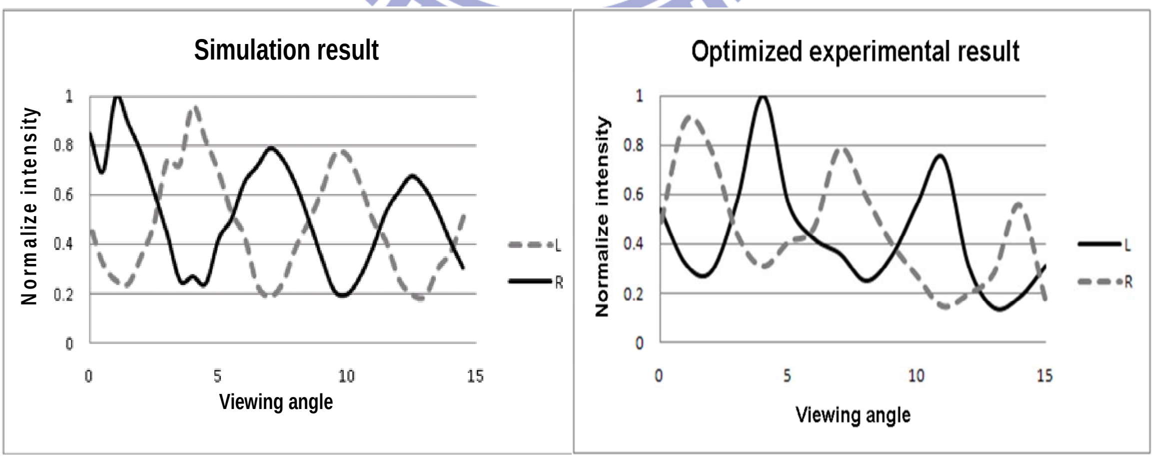


Fig.5- 14 The comparison between the simulation result and the optimized experimental result

5.4 Step three: Improvement by DCR (digital crosstalk reduce) method

In order to reduce the crosstalk issues for the pattern polarizer and quarter wave plate light leakage issues, we used the DCR (digital crosstalk reduces) [22] method to reduce the crosstalk value.

In previews experimental results, the light leakage from the pattern polarizer and quarter wave plate in red light is 30%, in green light is 15% and in blue light is 30%. We used the DCR method to decrease the image intensity in red light for 30%, in green light for 15% and in blue light for 30%. Finally the DCR method decreased the crosstalk value form 20% to 15%. The crosstalk value was decreased through the DCR method, but the light intensity was decreased too; this is a trade–off between the brightness and the crosstalk value.

5.5 Experimental pictures

We made a simple dual-view image as shown in Fig.5- 15. The dual-view image combined two different images with left and right eye images. We projected this image to the proposed display, and used a camera to record in left and right eye position. In Left eye position the picture showed a left eye image position as shown in Fig.5- 16 (a). In right eye position the picture showed a right eye image position in Fig.5- 16 (b).

Obviously, the proposed display unable separate left and right images correctly before improvement, there were some reflected light on the pattern polarizer; we can not see the high quality separated image. We placed an adjustment polarizer in front of the camera, at the picture shows in Fig.5- 17 (a) (b). After placing an adjustment polarizer in front of the camera, the left and right image were separated by this display correctly. When observers stood in the correct position, their right eye and left eye saw two different images without wearing glasses.

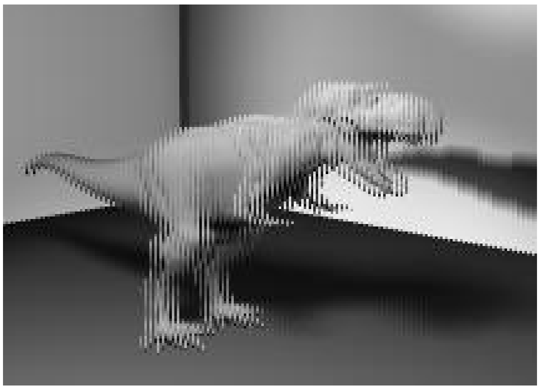


Fig.5- 15 The image combining the left and right eye image.

(a) (b)

Fig.5- 16 Before placing an adjustment polarizer in front of the camera (a) Left eye image in left position. (b) Right eye image in right position

(a) (b)

Fig.5- 17 After placing an adjustment polarizer in front of the camera (a) Left eye image in left position. (b) Right eye image in right position

The Fig.5- 15 is difficult to see the improvement through the DCR method; we used a simple image as shown in Fig.5- 18. The Fig.5- 18 combined the left eye image "1" and the right eye image "2". We used the camera to take a picture at the left eye position as shown in Fig.5- 19. The original experimental result is shown in Fig.5- 19 (a). The number "1" and "2" is visible in left eye position. After we placed an adjustment polarizer in front of the camera as shown in Fig.5- 19 (b), the "2" is reduced through the adjustment polarizer in left eye position, but the "2" is still visible. We used the DCR method to reduce the crosstalk as shown in Fig.5- 19 (c); we can see the "2" is almost invisible in left eye position.

Fig.5- 18 The simple image combining the left “1” and right eye image “2”.

(a) (b) (c)

Fig.5- 19 The comparison with the crosstalk intensity in left viewing position (a) The original experimental result (b) Improved result by adjustment polarizer (c) DCR improved result

5.6 Summary

The crosstalk of the experimental results was 45%, because of the reflected image issue on the pattern polarizer; the reflection destroyed the image light reflected from the AgO screen.

Step one: To improve the reflection image issue through a pattern polarizer, we placed an adjustment polarizer in a polarization direction which was perpendicular to the projected light. The adjustment polarizer blocked the reflected image on pattern polarizer; the adjustment polarizer decreased crosstalk and increased the image quality. The experimental results of the improvement method show crosstalk at 30%.

Step two: The crosstalk value was too large for observers to perceive the 3D effect. We varied the pattern polarizer aperture size from 2mm to 1.2mm. And the crosstalk decreased to 20%.

The crosstalk value of simulation results was less than 5%, but the greatest experiment results were 20%. There were three major issues.

The pattern polarizer and quarter wave plate light leakage was different in different wavelength causing different crosstalk values in different color light. The smallest crosstalk value was 20% of 480nm. The AgO screen did not scatter all projected light without changing the light polarization state; ten percent of projection light changed the polarization state and caused the crosstalk. The projector had an alignment issues and contract ratio issue; these two issues caused low image quality and crosstalk.

Step three: We used the DCR method to reduce the crosstalk from 20% to 15%, but the DCR method decreased the light intensity too. This is a trade-off between the crosstalk and the brightness.

The comparison about the crosstalk value variety as shown in Fig.5- 20, the original experimental result is 45%, the improved result by adjustment polarizer is 30%, and the optimized crosstalk value is 20%. Finally, the DCR method improved result is 15%.

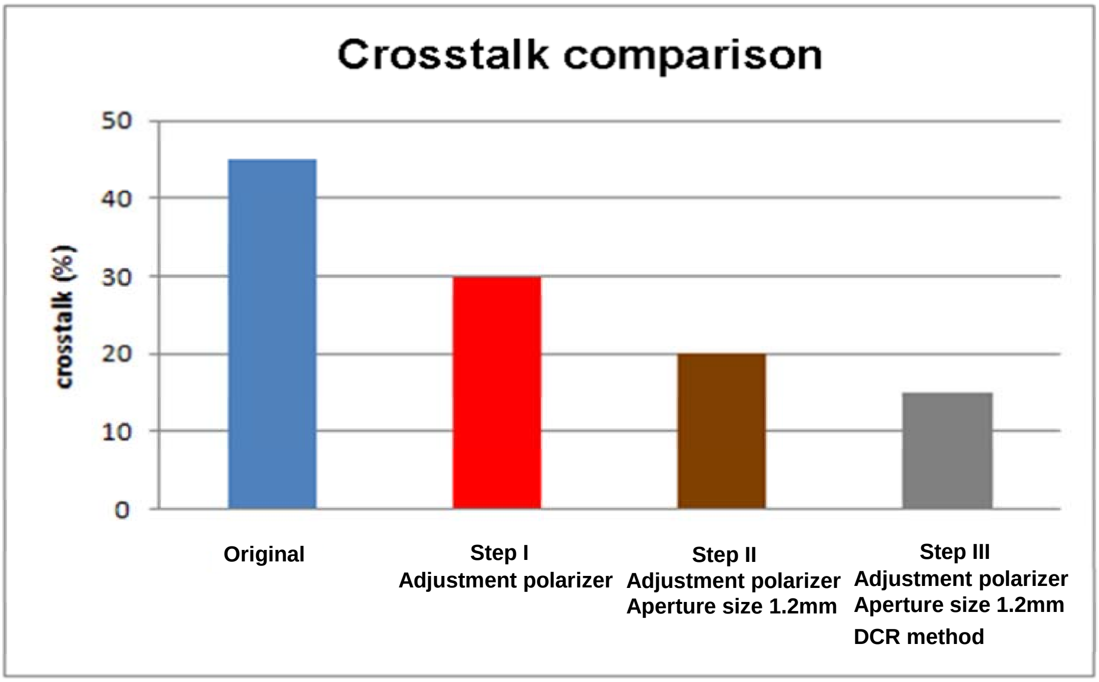


Fig.5- 20 The comparison about the crosstalk by improved methods

Chapter 6

Conclusions and Future Works

6.1 Conclusions

A projection type auto-stereoscopic 3D display is designed; this structure used a patterned polarizer, a quarter wave plate, an AgO screen and a polarization projector to achieve a 3D projection system without wearing glasses. The design formula of the proposed display is similar to the parallax barrier auto-stereoscopic display; we used the parallax barrier design formula to design this structure model.

From the simulation by the lighttools, the crosstalk was 5% in direct viewing position, and the crosstalk was 20% in wide viewing angle, we changed the polarizer aperture size to improve the crosstalk and viewing window, the optimized aperture size was 1.2mm, but there are some trade-off in the crosstalk and light efficiency. This structure made the multi-view system easily. We have done the 4 view multi-view simulation; the average crosstalk was less than 10%.

The experiment results showed the crosstalk was 45% in direct viewing, because of the reflected light on pattern polarizer. We suggested some improvement methods to improve the issues. In step one: we placed a 135° adjustment polarizer between the observers and screen to decrease the crosstalk to 30% and increase the image quality. In step two: we changed the pattern polarizer aperture size form 2mm to 1.2mm to decrease the crosstalk to 20%. There were still some issues caused the crosstalk, such as pattern polarizer and quarter wave plate light leakage issues, AgO screen light leakage issue, projector alignment and contrast ratio issues. The image demo showed this proposed structure separated the left and right image in the fixed position. In step three: we used the DCR method to reduce the crosstalk from 20% to 15%.

This system made the multi-view system easily by changing the pattern polarizer aperture size. And the panel size is larger than the conventional auto-stereoscopic displays. This structure can use in the large size movie theater screen, medical examine, entertainments, and commercial application.

6.2 Future works

The projector alignment and contrast ratio is not good enough, this conditions made the measurement error in the experiment. We will use the precise DLP projector to measure the actual crosstalk value. The pattern polarizer in the experiment is too easy to misalign; we will find the better pattern polarizer to reduce the reflection issues and the alignment issues.

To reduce the reflected light on pattern polarizer, we placed the adjustment polarizer in front of the observers to improve the reflection issue through the pattern polarizer. In order to project light to the screen totally, the adjustment polarizer did not block the projected light path, so the adjustment polarizer was placed at the back of the projector. In the proposed structure, the projection distance is 4m; 4m is too far for observers to see the high quality 3D image.

We will use the super close projector to reduce the adjustment polarizer distance as shown in Fig.6- 1. The super close projector will reduce the projection distance from 4m to 1m. The adjustment polarizer and observer’s viewing distance will be reduced. The observer will see the better 3D image by using the super close projector.

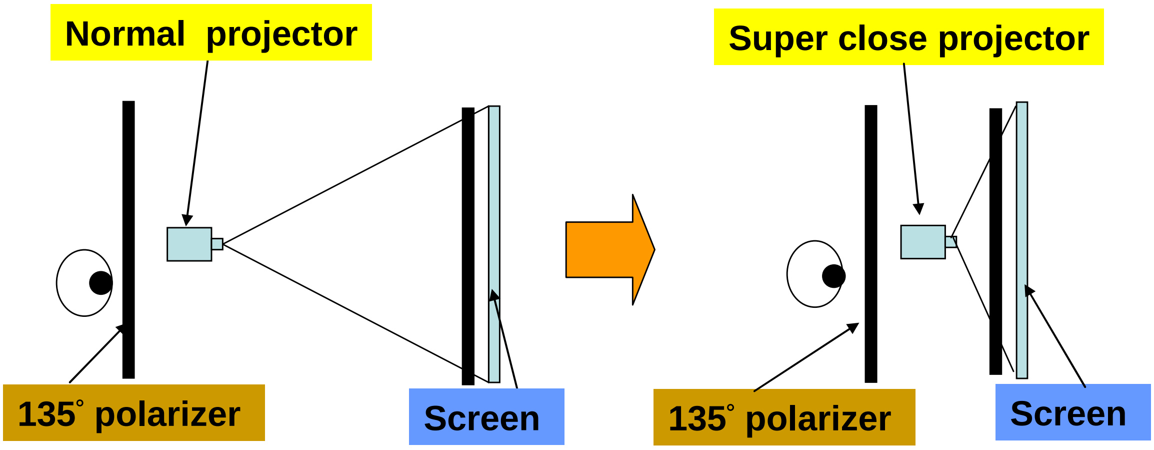


Fig.6- 1 The comparison between the normal projector and super close projector

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