Research on improving VAC of auto-stereoscopic 3D display via monocular multi-view

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Abstract—The auto-stereoscopic 3D display technology is the most widely used 3D display technology nowadays, but its problem of vergence-accommodation conflict (VAC) remains to be solved. This paper proposes a novel method to solve this problem via monocular multi-view, aiming to alleviate the discomfort caused by VAC. By utilizing the light splitting of the parallax barrier and a specific rendering algorithm, we generate multiple images from different angles in a viewing zone. In this way, each eye can receive more than two images, thereby easing VAC through the automatic blurring adjustment of human eyes.

1. INTRODUCTION

From the physiological perspective, human stereoscopic vision mainly includes four physiological cues, namely, focus adjustment, convergence change, binocular parallax, and motion parallax [1-2]. In 1902, F. E. Ives first proposed a binocular parallax auto-stereoscopic 3D display technology based on a parallax barrier, which is still in use today. For example, the 17-inch 8K light field displayer produced by Japan's JDI Company in 2018 was developed based on this technology [3]. Lenticular lens array-based auto-stereoscopic 3D display technology is currently the most widely-used technology. It shares the same mechanism as the parallax barrier as both are realized based on binocular parallax. However, this type of 3D display usually causes visual fatigue, blurring, and even physical discomfort for long-time viewers. That is because the convergence angle and focus adjustment of the human eye are matched under normal circumstances (that is, when viewing a real scene), as shown in Fig. 1; however, when a person views an auto-stereoscopic display, 3D scenes are automatically synthesized in the brain after both eyes see the pictures from different angles. When people pay attention to objects of different depths of field, the brain will provide feedback on the depth information to the eyes, and the eyes will unconsciously perform a physiological response, adjusting the convergence angle to the given depth position. But at that time, the eyes are still focused on the display screen, which contradicts the natural state of human eyes, leading to eye fatigue and even headache after long-time viewing [4-5]. In recent
years, many methods, such as multifocal, varifocal, multi-layer, and focal surface displays, have been proposed to solve the VAC problem [6-8]. Nevertheless, these methods are all based on complex optical systems and thus face challenges for wide adoption [9-10]. The auto-stereoscopic display technology via monocular multi-view proposed in this study, with a parallax barrier structure, enables one human eye to see multiple viewpoints at the same time by reducing the viewing area and increasing the number of viewpoints and motion parallax, thereby alleviating the VAC problem through adaptive regulation of human eyes.

Figure 1. Vergence accommodation conflict (VAC)

2. PRINCIPLES AND METHODS
Under normal circumstances, the parallax barrier-based auto-stereoscopic display can send the images correspondingly to the left and right eyes. The left eye can only see the left view, while the right eye can only see the right view. The views of two eyes are arranged alternately in a viewing zone. This paper designs to increase the number of viewpoints in a viewing zone until one eye can receive light from more than two viewpoints, as shown in Fig. 2. In fact, the number of viewpoints in a viewing zone mentioned here can be understood as the viewpoint density, which is expressed by the number of viewpoints per unit distance at the optimal viewing distance in our scheme. For example, in conventional auto-stereoscopic display, the binocular viewpoint period is approximately 13 cm (twice the interpupillary distance; the average interpupillary distance of a person is 6.5 cm). One period corresponds to two viewpoints, so the viewpoint density is 0.15/cm.

In order to increase the viewpoint density, the number of viewpoints should be increased and the viewing zone should be compressed. Therefore, we compressed the viewing zone to the range within the twice the interpupillary distance by adjusting the viewing distance, grating pitch, and thickness of the spacer glass. In addition, the non-integer pixels pitch size and the slant barrier were used to increase the maximum number of natural viewpoints to above 86. If only the pupil's limiting effect on light is considered, one eye can see two views at the same time and the viewpoint density at this time is 4.15/cm under the condition that a pupil's diameter is set as 0.3 cm (the average value under normal ambient light). Thus, the auto-stereoscopic display via monocular multi-view requires a viewpoint density greater than 4.15/cm. However, the pupil of the human eye is located behind the cornea, which is responsible for 70% - 80% of the focusing ability, so the light has already converged once before entering the pupil. In addition, it is impossible to achieve perfect beam splitting either using the parallax barrier or the lenticular lens array. Viewpoints crosstalk always exists, so the actual number of views seen by one eye should be greater than the number calculated previously. In addition, the monocular multi-view refers to one eye receiving multiple views, but it does not necessarily mean that the same view can be seen by the left and right eyes at the same time, and the viewpoint crosstalk should be minimized.
3. RESULTS AND DISCUSSION

This paper adopts parallax barrier made of film to conduct experimental verification to analyze the actual number of viewpoints and crosstalk. Three kinds of parallax barrier were designed: 1) parallax barrier with a pitch of 26/3 pixels and an aperture ratio of 30%; 2) parallax barrier with a pitch is 26/3 pixels and an aperture ratio of 10%; 3) parallax barrier with a pitch of 35/3 pixels and an aperture ratio of 10%. A line-type diagram was made as the source sequence diagram, as shown in Fig. 3a. White horizontal lines were drawn on a black background at difference positions on each sequence diagram. To facilitate identification, we sequenced the positions of the white lines from the top to the bottom. Then, the sequence diagram is rendered according to the algorithm mentioned earlier and the results are shown on a slit-mounted display. At this time, the number of stripes on the screen that can be seen by one eye is the actual number of viewpoints. For example, the monocular viewpoints for the parallax barrier with a pitch of 26/3 and an aperture ratio of 10% at 8 viewpoints is 2. By adjusting the focal length and aperture size of the camera, we made the number of lines taken by the camera the same as that of lines seen by the human eye. In this way, we simulated the results recorded by the human eye, as shown in Fig. 3b.

The comparison between the rendering results of three kinds of parallax barrier with different viewpoints is shown in Fig. 4. Under the condition of two viewpoints, two lines can be seen through the parallax barrier No. 1. This is exactly what we mentioned earlier, that is, the same view is seen by both the left and right eyes. Through parallax barrier No. 2 and No. 3, we can only see one line, which indicates that the aperture ratio will affect the degree of crosstalk. However, it should be noted that the aperture ratio also determines the light transmittance and affects the display brightness. Therefore, it is necessary to take into account the brightness while reducing the crosstalk. We also noticed that with the same number of rendering viewpoints and the same aperture ratio of 10%, the number of lines seen by the larger-pitch parallax barrier is smaller, indicating a smaller viewpoint crosstalk. However, it should also be noted that the increase in the pitch of the parallax barrier will cause a decrease in the display resolution. The results show that the parallax barrier No. 3 already achieves monocular two viewpoints when rendering at eight viewpoints.
The method of interpolation was used on the depth map and the zero plane was selected at a position of 50% depth of field. We obtained a series of source sequence diagrams with different numbers of viewpoints, and performed rendering using parallax barrier No. 3. The result is shown in Fig. 5. It can be seen that when there were fewer viewpoints, the foreground and background ghosting was more obvious. As the number of viewpoints increased, the ghosting parts became continuous, causing visual blurring. Under this circumstance, the human eyes made adaptations and focus so as to approximately match the focus and the convergence angle, thereby easing the discomfort caused by VAC.
Fig. 5 shows that the monocular multi-viewpoints caused blurring, but not in the zero-plane position, such as the position of the dial plate in the watch. To analyze this phenomenon, we designed a resolution board to test the effect of depth of field on resolution. First, we drew a resolution board, as shown in Fig. 6a, which is rendered by 55 viewpoints from the depth map of the 2D resolution plate shown in Fig. 6b. Then, after observing the set of stripes that can be recognized at positions corresponding to different depths of field, we can determine the resolution accordingly. As Fig. 7 shows, the resolution is lower at a position farther from the zero plane, and the resolution of the zero plane is actually the 2D resolution of the display screen plus the parallax barrier.

4. CONCLUSION
This study proposes a method to solve the VAC problem in auto-stereoscopic display and analyzes the underlying mechanism. Parallax barrier experiments verified that monocular multi-viewpoints can introduce different degrees of blurring effects to different depths of field, thereby easing the discomfort caused by VAC through adaptive adjustment function of human eyes. However, blurring will cause a reduction in resolution. Therefore, this method is not applicable to rendering of views with a large depth of field.

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