A 2D/3D Hybrid Integral Imaging Display by Using Fast Switchable Hexagonal Liquid Crystal Lens Array

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ABSTRACT

The paper proposes a new display which could switch 2D and 3D images on a monitor, and we call it as Hybrid Display. In 3D display technologies, the reduction of image resolution is still an important issue. The more angle information offer to the observer, the less spatial resolution would offer to image resolution because of the fixed panel resolution. Take it for example, in the integral photography system, the part of image without depth, like background, will reduce its resolution by transform from 2D to 3D image. Therefore, we proposed a method by using liquid crystal component to quickly switch the 2D image and 3D image. Meanwhile, the 2D image is set as a background to compensate the resolution.. In the experiment, hexagonal liquid crystal lens array would be used to take the place of fixed lens array. Moreover, in order to increase lens power of the hexagonal LC lens array, we applied high resistance (Hi-R) layer structure on the electrode. Hi-R layer would make the gradient electric field and affect the lens profile. Also, we use panel with 801 PPI to display the integral image in our system. Hence, the consequence of full resolution 2D background with the 3D depth object forms the Hybrid Display.

Keywords: Light Field, Liquid Crystal Lens Array, High Resistance Layer, Integral Image, Hybrid Display

1. INTRODUCTION

In several decades, as the display technology getting more and more improved, there are many explosive development in three-dimensional (3D) displays technologies. Nowadays, the 3D displays technologies are applied widely in our life, such as exhibitions, movies, advertisements and so on. Due to 3D displays can make observers preserve depth information, compared with traditionally planar display, 3D display technologies could be believed to become the main stream in the next generation.

Depend on wearing 3D glasses or not, 3D display technologies could be divided into two types, stereoscopic and auto-stereoscopic. Besides, there are several 3D techniques to create 3D images not by binocular disparity. These techniques reconstruct the image information of 3D objects in the space, which create a 3D image, such as volumetric, holography, integral image and so on. Take holography for example, it use coherent light to illuminate an object and records the interference fringe pattern between the object beam and reference beam. However, holography needs small pixel size (about 0.2μm). Also, it's hard to achieve in flat panel display [1]. For volumetric 3D display, the biggest defect is the volume and interactive issue [2]. Others, integral image can capture the image information of an object from many different perspectives into individual images. Those individual images are usually called elemental images. If we use a display to show those elemental images with the same micro-lens array, a virtual 3D object will be reconstructed as a 3D image as shown in Figure 1. However, in order to preserve more angle information, integral image must sacrifice the spatial resolution of reconstructed image [3].

In conventional 3D display technologies, the image can be briefly divided to background and foreground with different depth information. In other words, the image depth of background often close to display panel, which almost equal to zero. However, due to the disparity of 3D in conventional 3D display, the resolution of background would be reduced when display 3D image. Hence, the resolution reduced issue must be solved.

Therefore, we propose a new 3D display called Hybrid Display to solve the background issue. The Hybrid Display use time-multiplexed method to switch 2D mode and 3D mode. In Hybrid Display system, we use full resolution image in 2D mode to compensate the resolution of integral image which is created in 3D mode. By using liquid crystal lens array and Twisted-Nematic cell (TN cell) components to quickly switch the 2D mode (full resolution 2D image) and 3D mode (integral image). Therefore, observers can see 3D image which has full resolution background by visual persistence.

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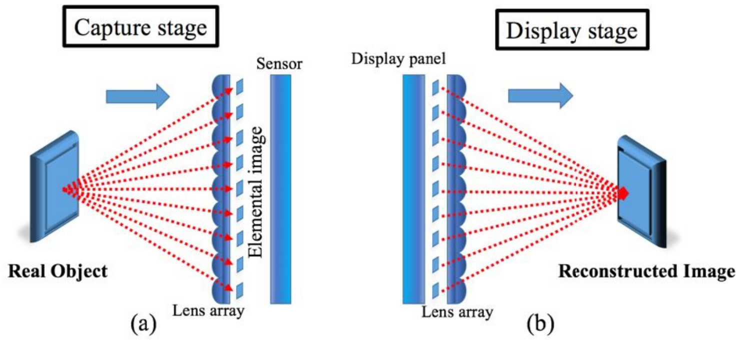

Figure 1. Integral image system in (a) capture stage, sensor records elemental image which has angle information of real objects; (b) display stage, display panel will display elemental image. After passing through lens array, the true 3D image will be reconstructed as real image in the space.

2. METHOD

The purpose of this paper is to use full resolution 2D image to compensate resolution of integral image, and observers could see 2D and 3D images by visual persistence. As we mentioned above, the switchable method in our Hybrid Display achieved by LC lens array and TN cell components. The following parts will show the principle of Hybrid Display in 2.1, 2.2 about the hexagonal LC lens array with high-resistance layer and TN cell.

2.1 Principle of Hybrid Display

In the design of this paper, we could divide hybrid display by two modes, 2D mode and 3D mode. In 2D mode, as Figure 2., the display will show full resolution 2D background image. The linear polarized light pass through the LC lens array (turned on) and TN cell (turned off), and its direction will be rotated 90 degrees. Next, due to the direction of polarized light is perpendicular to alignment direction of LC lens array, LC lens array will not have lens function. Because LC lens array has lens function when polarization direction of incident light is parallel to alignment direction of LC. Thus, the observer will see the full resolution 2D background image.

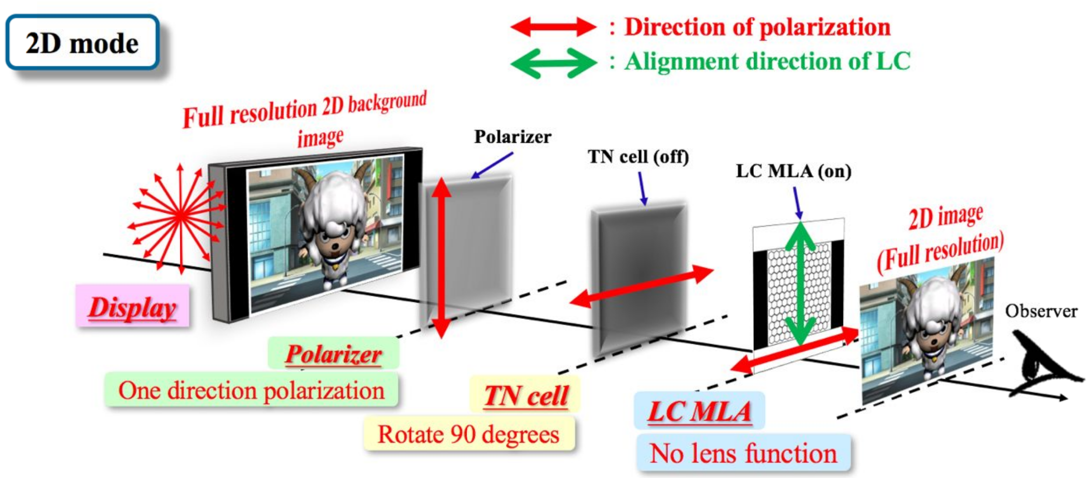

Figure 2. 2D mode in hybrid display

On the contrary, in 3D mode, when linear polarized light pass through TN cell (turned on), polarization direction will pass without rotation as Figure 3. Because the direction of polarized light is parallel to alignment direction of LC, LC lens array will have lens function. Therefore, observer will see real image which is reconstructed from integral image. By switching two modes, what we expected is that observers see the full resolution 2D background image with depth information like Figure 4.

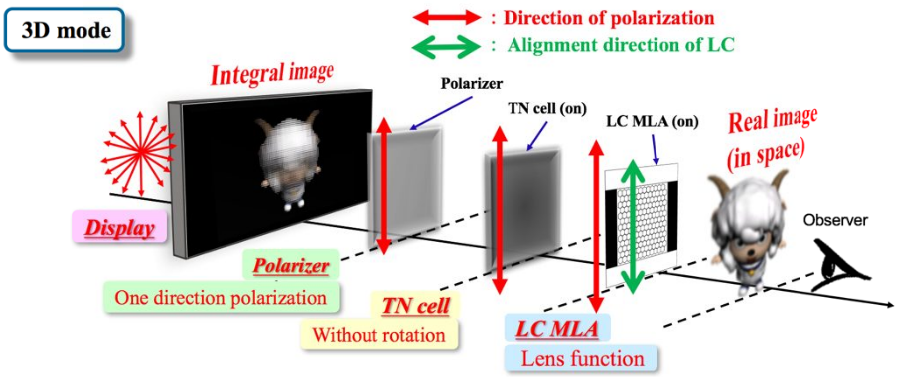

Figure 3. 3D mode in hybrid display, observer will see the real image which is reconstructed in the space

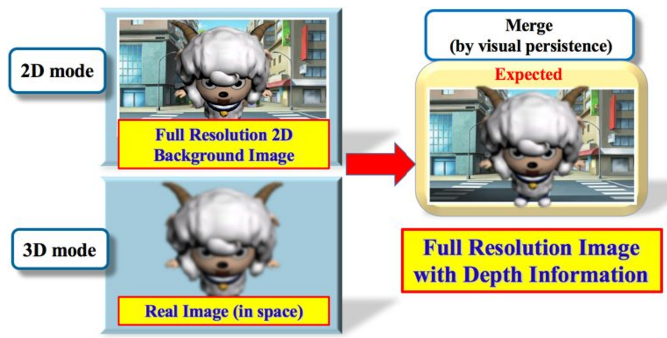

Figure 4. Merging two modes image by visual persistence, observer will see full resolution image with depth information

2.2 Hexagonal LC lens array with high-resistance layer and TN cell components

So far, LC lens array has been developed for decades. To put it briefly, LC lens array has lens function when voltage is applied on electrodes as Figure 5.(a). For conventional LC lens array, which has external electrode has higher driving voltage (> 40 Vrms). Therefore, multi-electrodes LC lens has been proposed [4][5], utilizing a large number of electrodes to significantly control the electrical field on LC layer to get lower driving voltage. However, this kind of design has complex driving by operating different voltage in different electrodes respectively. To get the structure simple and to have lower operating voltage, we use hexagonal LC lens array with high-resistance (Hi-R) [6] [7] layer which not only be easy to fabricate but also needs lower operating voltage. Besides, one of it's characteristic is voltage and frequency controllable for different focal lengths. Moreover, Hi-R layer has another characteristic is that it can make LC lens array get the gradient electrical field on the boundary electrode. Therefore LC lens array would have ideal lens shape to perform netter lens function, as Figure 5.(a). shows.

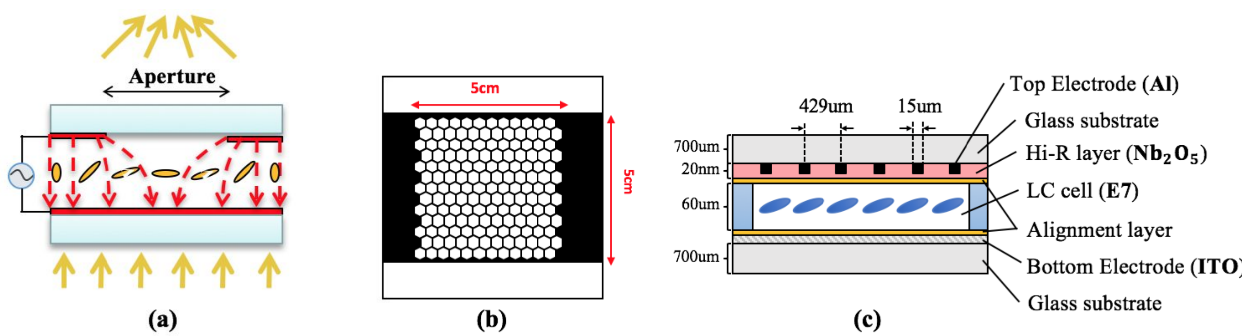

Figure 5.(a) LC lens array can focus the light. Due to Hi-R layer, the boundary electrode has smooth electrical field (b) top view(c) side view of our LC lens array structure

In our LC lens array structure like Figure 5.(b)(c), the size of lens array is about 5cm x 5cm, aperture size of each hexagonal lens is 429μm. We use aluminum(Al) as top electrode, ITO as bottom electrode. There is Hi-R layer on top electrode in. LC material we use is E7. Besides, alignment layer between top and bottom electrodes is anti-parallel and Cell gap of LC cell is 60μm.

Moreover, the response time of LC lens array needs 60hz(16ms) to fast switch two modes and achieve visual persistence in human eyes. In our LC lens array, due to conform the focal length and lens quality we want, we chose 60μm as cell gap. The cell gap was too thick resulting in the response time is not as fast as 16ms. Therefore, switch function in Hybrid Display would be achieved by TN cell.

TN cell can be briefly divided by two state, voltage on state and voltage off state. As Figure 6.(a), TN cell has twist characteristic which means the alignment of TN cell on top and bottom electrode is perpendicular when voltage turned off. Therefore, the direction of polarized light will rotate 90 degrees. On the contrary, like Figure 6.(b), in the voltage on state, TN cell will arrange straightly with voltage turned on. Thus, when light pass through TN cell, polarization direction won't be changed.

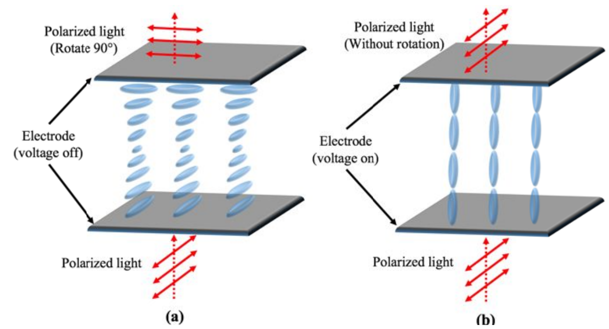

Figure 6. In TN cell (a) voltage off state, light polarization will rotate 90°; (b) voltage on state, light polarization will not be rotated , passing through TN cell.

3. RESULTS

In the previous section, we use LC lens array with high-resistance layer and TN cell components as a role to switch 2D and 3D mode in our Hybrid Display. Besides, due to our LC lens array has Hi-R layer, the operating voltage can be lower than 10Vpp.

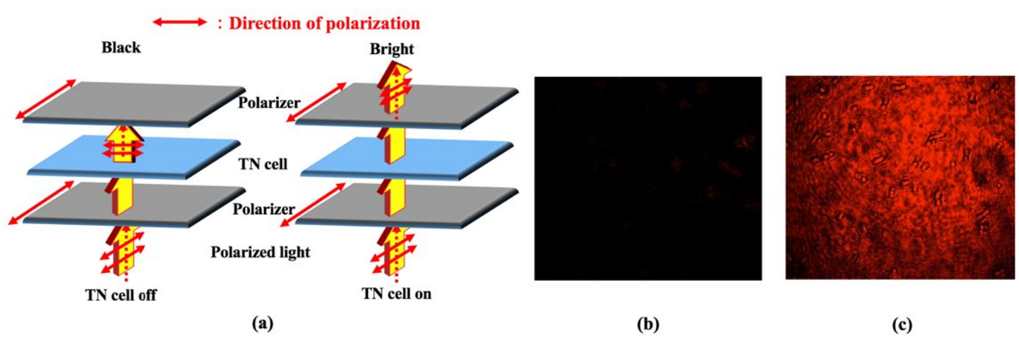

Figure 7.(a) TN cell turned off, light polarization will be rotated 90°, TN cell turned on, light polarization will not be rotated 90°; (b) polarized light rotate 90°, screen become black; (c) polarized light will pass, screen become bright

In Figure 7.(a), top and bottom polarizers has some polarization. Polarization direction of light will be rotated 90 degrees with TN cell turned off. Therefore, the screen would become black like Figure 7.(b). On the contrary, polarization direction of light will not be rotated degrees with TN cell turned on. Thus, the screen would become bright as Figure 7.(c).

Then we combine LC lens array with TN cell as Figure 8. (a). When TN cell turned off, polarization direction of light will rotate 90 degrees, which is perpendicular to alignment direction of LC, thus LC lens has no lens function. As Figure 8.(b), the LC cell will arrange straightly with TN cell turned on. Polarization direction of light will be parallel to rubbing direction of LC. While the polarized light pass through the LC lens array, the light in LC cell will produce different phase retardations, because the birefringence of LC molecules. Therefore, fringe pattern which can observer relative phase retardation of LC lens array will be recorded by photo detector. Due to LC lens array combined TN cell(turned on) has lens function, light will be focus to a point as Figure 8.(c). Under LC lens array combined TN cell has lens function, let direction of polarized light be parallel to rubbing direction of LC lens array. We can get the focus point of LC lens array, which can verify components (LC lens array and TN cell) can actually focus the light.

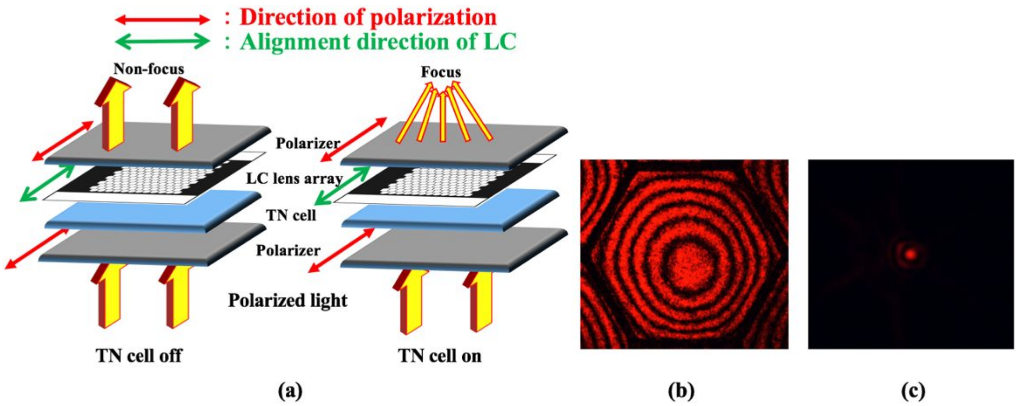

Figure 8. (a) Combine LC lens array with TN cell; (b) LC lens array has lens function with TN cell turned on and produce fringe pattern by LC phase retardation; (c) LC lens array focus the light to a point

Before setting Hybrid Display, we make the integral image by software first. As Figure 9.(a), there is an integral image(including sky, airplane, island), just like the image of conventional 3D display. Besides, it will input on display panel. After being reconstructed to real image by LC lens array, it will be compared with the image of Hybrid Display in Figure 10. As we mentioned above, Hybrid Display has two modes. In 3D mode, the integral image of foreground (island) will be displayed on display panel like Figure 9.(b). In 2D mode, full resolution 2D background image (including sky, airplane) like Figure 9.(c), will also input on display panel.

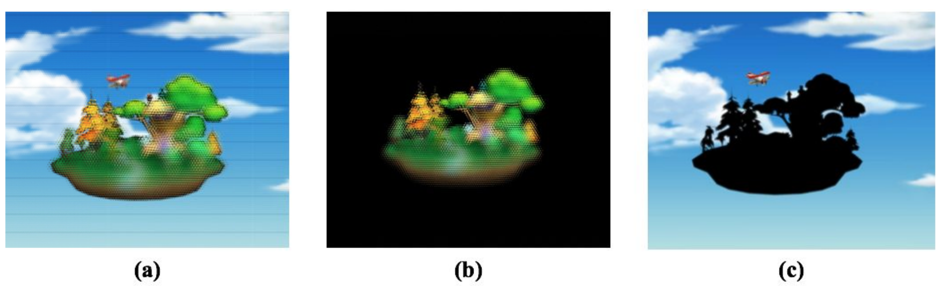

Figure 9. (a) conventional integral image of background and foreground; (b) integral image as foreground used in 3D mode; (c) full resolution 2D background image used in 2D mode

After ensuring the image of 2D mode and 3D mode, we implement Hybrid Display. Figure 10. were all taken by Canon 600D with F5.6 and image size of Figure 10.(a)(b)(c)(d) is 4.5cm×4.5cm. Image size of Figure 10.(e)(f) is 1cm×1cm. In 3D mode, the integral image of island in Figure 10.(a), would be reconstructed to real image as Figure 10.(a) shows. Next, as the switch function of TN cell and LC lens array, we could switch the clear full resolution 2D background image in 2D mode like Figure 10.(b). in the second moment.

By using LC lens array combined with TN cell to fast switch two modes, observer could see full resolution 2D background image (sky and airplane) with depth information(island) as Figure 10.(c). As we mentioned above, the background image in conventional 3D display has reduced resolution issue. Therefore, the conventional integral image as Figure 10.(a), was reconstructed to real image(island, sky, airplane) as Figure 10.(d) by using LC lens array.

With more detail information in the yellow box of Figure 10.(c)(d), shown in Figure 10.(e)(f), we can easily distinguish the details information of airplane in Figure 10.(e) are better than Figure 10.(f). These results verify our hybrid display could achieve the resolution compensated in background image.

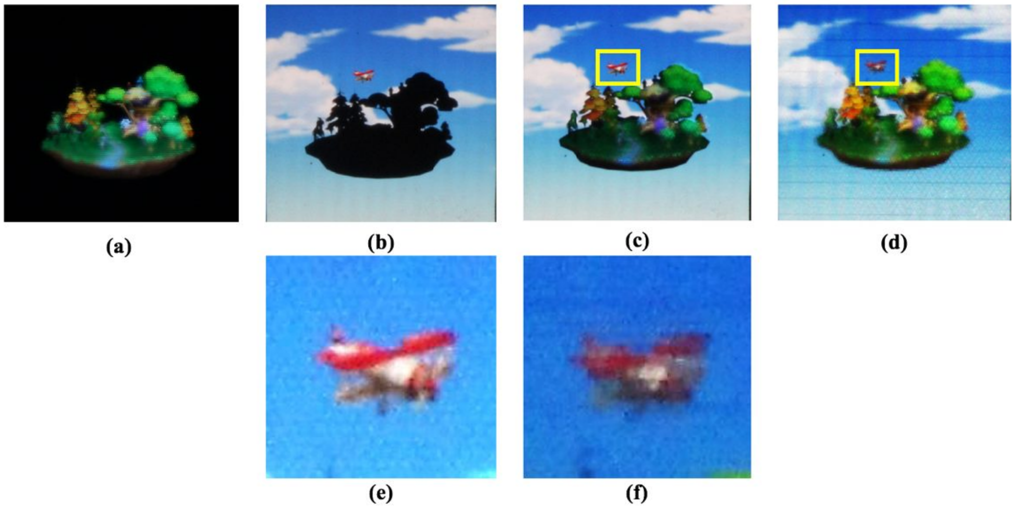

Figure 10. (a) reconstructed image in the space in hybrid display 3D mode; (b) full resolution 2D background image in hybrid display 2D mode; (c) image with full resolution background 2D image of sky and airplane, also real image of island by visual persistence (d) all real image has decreased background resolution; (e) magnify the yellow box image of Figure 10.(c); (f) magnify the yellow box image of Figure 10.(d).

4. DISCUSSIONS

In previous section, we apply LC lens array to Hybrid Display. However, there are some issues have space to improve

In device part, the lens quality of LC lens array is not good enough to produce aberration. As we mentioned above, lens quality of LC lens array will straightly affect the image quality in Hybrid Display. We may consider the roughness of Hi-R layer, which will also affect the lens quality. Due to response time of LC lens array (2s) is not fast enough to fast switch two modes in Hybrid Display. Although we can reduce cell gap from 60μm to 5μm, so that response time of LC lens array can achieve about 15ms. But, the lens quality of LC lens array would get worse. Therefore, switch function in Hybrid Display would be achieved by TN cell. Another straight forward way to speed up response time is change LC material. From E7 LC to blue phase LC, response time of LC lens array be believed to speed up. [8]

Although we achieve Hybrid Display which can let observer see full resolution 2D background image with depth information by visual persistence, there are still some issues exist. First, we can easily observe that Figure 10.(c) has luminance issue, which means brightness of 2D mode image is not coordinate with integral image in 3D mode. Therefore, it is necessary to adjust the brightness of image in two modes. Others, Figure 10.(c) looks un-nature at the edge of reconstructed image because the boundary of island in 2D background is too sharp. The one of method is blurring the edge of island in 2D mode background image.

5. CONCLUSION

In this paper, we propose novel display which could switch 2D and 3D images on a monitor, and we call it as Hybrid Display. There are two modes (2Dmode、3D mode) set in Hybrid Display. In 2D mode, observer could see full resolution 2D background image by operating LC lens array (turned on) combined TN cell (turned off). In 3D mode, observer could see reconstructed image which reconstructed from integral image as foreground by operating LC lens array (turned on) combined TN cell (turned on). Combine LC lens array with TN cell to fast switch two modes, observer would see full resolution 2D background image (sky and airplane) and true 3D foreground image (island) by visual persistence. Consequently, we can perceive more detail information of background image on Hybrid Display as Figure. 10(e). Furthermore, there are some performance can be improved such as lens quality, response time of LC lens array, image quality and image brightness in Hybrid Display.

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