Improved Design to Reduce Sparkles in 3D Light-Field Displays

Abstract

3D light filed display of 6K resolution was achieved for automotive application. Sparkles were observed while presenting delicate structures. The origin of the sparkling issue was studied by simulation based on ocular point spread function. The simulation results coincided with the actual performance, and method of improvement in design was further proposed. **Keywords:** Anti-sparkle, Light Field 3D

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Objective and Background:

3D light field technology, also known as integral imaging technology, is a popular 3D display solution for presenting autostereoscopic vision with special optical design and image rendering [1]. Comparing with common multi-view 3D displays, the 3D light-field display provides enhanced continuity in visual performance, but with a relatively higher resolution loss. Recently, 4k resolution has become very common in the market even in medium-sized display products, making it possible for 3D light-field displays to push the 3D resolution approaching the limit of human-eye. Nevertheless, the visual performance of 3D light-field displays needs to be considered carefully as well for displaying delicate images.

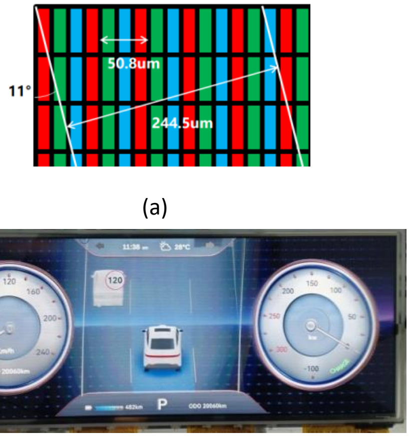
Here we demonstrate a 3D light-field display based on a 6k resolution display panel. We found uneven color points frequently exist in the area of delicate images. Since the unevenness is similar to sparkling issue of anti-glare film in appearance, we call the phenomenon "sparkle".

We proposed a simulation process based on ocular point spread function (PSF) to analyze the sparkling issue. The simulation results are consistent with the display performance. Optimized design is proposed based on the simulation.

Design and fabrication:

12.3inch 3D display module is designed following the integral imaging method. A sheet of resin film with cylindrical lens array imprinted is attached on a display panel to form 3D image. Display resolution of the panel is 5760 x 2160, supported by a pixel pitch of 50.8um. The angle between the longitude direction of lens and the longitude direction of sub-pixel is 11°. The width pitch of lens array is 244.5um. The design can support light field rendering of a 3D image for ±15° viewing angle.

3D image free of Moiré effect with high brightness 800nits is achieved. The display module can support the application of automotive cluster display as shown in Figure 1.

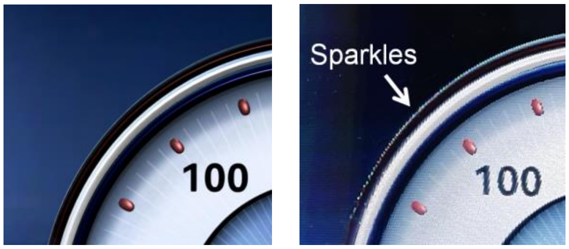


(a)

(b)

Figure 1 3D light field display module. (a) The design of pixel and 3D lens. (b) The 12.3inch display module with a 3D dashboard image displayed.

Uneven color points were found around some of the display boundary, as shown in Figure 2. The area of unevenness commonly exists around thin lines in the image formed by nearly one pixel. The phenomenon is actually severer for the observer than what is shown in the figure, which is possibly originate from the high brightness of the panel, or the higher imaging resolution of camera than that of the human eyes.



(a) (b)

Figure 2 Sparkles in the 3D image

Analysis:

Sparkle will appear in many different conditions. In the realm of display technology, sparkle is primarily attributed to uneven color or brightness in the light source, often resulting from material transmittance and diffraction. However, when considering 3D scenarios, the complexity is amplified. Light field 3D technology itself necessitates the emission of distinct light at varying angles, which consequently increases the likelihood of color and brightness inhomogeneity. This paper investigates the mechanisms behind 3D sparkle generation through the lens of both display and 3D image algorithms design.

2.1. Display design

The application of distinct voltages of varying magnitudes to the individual electrodes of a liquid crystal lenticular during its operation causes the liquid crystal to undergo a Z-axis flip to varying degrees. As light is passing through the LCL at various positions, the Z-axis flip influences the light, producing a certain degree of phase retardation. The magnitude of this retardation is directly equal to the effective refractive index difference “Δn ” between the liquid crystal and the product of the thickness of the liquid crystal cell “d”, so we can get the relationship: “Retardation=$\Delta n \cdot d$”. By transforming the retardation term in the above equation into an aspheric lens distribution, the effect of light convergence can be achieved. Through the property of liquid crystal lens, we successfully calibrate the equivalent curved surface distribution of the liquid crystal lens appearance (Figure 2). The calibrated liquid crystal lens has a smooth profile, essentially agreeing with the designed aspherical mirror appearance, realizing the function of a conventional lens. In addition, as our lens operates on electronic control, by adjusting the voltage distribution on the liquid crystal lens electrode, it can be independently calibrated for different devices. This process significantly reduces the cost of production, resulting in a financially beneficial solution.

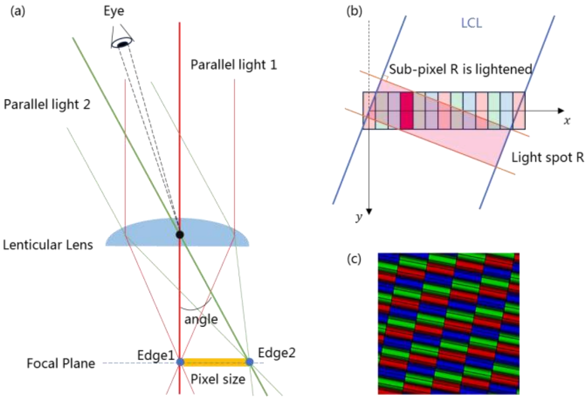


Figure 3 Principle of 3D lenticular display. (a) Because the emit angle will cover the pupil, eye will focus on the lens instead of infinity distance. (b) When a sub-pixel is lightened, we will see an elongated light spot on the lens. (c) the spot arrangement of white image in the 3D mode.

Calibrated LCL will focus on the pixels of the display image source. Theoretically, at the focal point of the lens, the pixels can emit parallel light due to the convergence of the lens. However, due to the size of the pixel itself, the light emitted from the lens diverges at a certain angle. The viewing surface corresponding to the divergence angle is often larger than the size of the pupil, resulting in the human eye focusing the 3D image on the liquid crystal lens instead of other positions in space. Therefore, the pixels we observe are the light spots on the lens.

2.2. 3D image algorithms

In the context of 3D displays, the illumination of light spots on the display screen is not organized in the physical RGB sequence, resulting in discernible disparity in the spacing between adjacent light spots of the same color. The directional relationship between the liquid crystal lens and the image source is pivotal in mitigating the occurrence of moiré and preventing color difference in the viewing angle. However, this arrangement also results in a stepped dislocation between light spots of the same color, which can be particularly noticeable in certain details (e.g., Figure 4(d) there are obvious color stripes at the edge of windows). The edge of the image disrupts the regular arrangement of light spots, causing sub-pixels of the same color to occupy an excessive amount of space. This can lead to a color difference at different positions, affecting

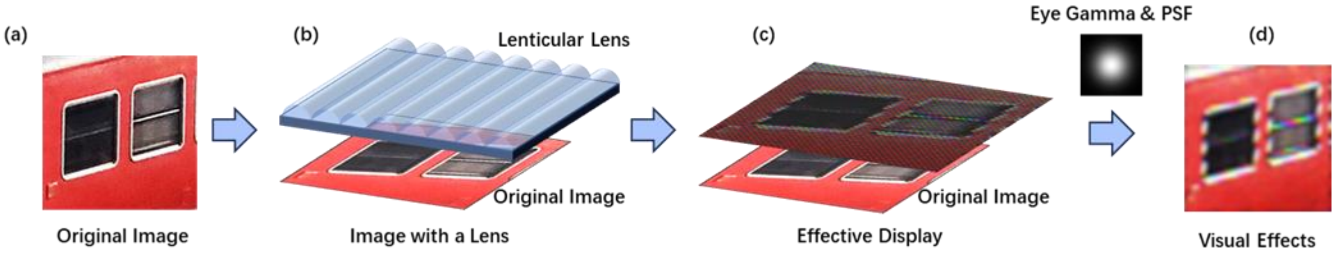


Figure 4 Simulated sparkle visual effects. (a) original image. (b) and (c) set the original image under the LCL lens and calculate the arrangement of light spot. (d) The result of simulation. Set a observer distance, consider the human eye's gamma and resolution limit.

the macro performance of the display. Furthermore, the image size is often small (typically only 1 to 2 pixels pitch of the display) and the disorder is often observed at the edge of the image with a high contrast difference, manifesting as color, brightness, or line irregularities when observed.

To tackle this issue, there is a potential solution that could be explored: firstly, the display pixel arrangement could be modified to conform to the actual RGB format, resulting in the more accurate distribution of lens light spots; secondly, the image source could be subjected to anti-aliasing, which may effectively decrease the occurrence of sparkle.

In conclusion, it is essential to identify accurately the root cause and exact location of the sparkle effect, regardless of whether the solution involves modifying hardware or algorithms. This should be carried out independently to ensure that the optimization process does not negatively affect the normal function of the display.

Simulation:

Due to the current fact that the evaluation of 3D sparkle mainly relies on the human eye, we should simulate the final visual effects of image. When considering the visual effects observed by human eyes, theoretically, a series of factors need to be taken into account such as diffraction, defocus, aberrations, polychromatic light, etc. [3]. However, Those operations require a significant amount of resources and computation. To simplify the calculation, we use PSF and gamma function to simulate the actual image effect and the results match well [Figure 5 (c) and (d)]. According to limit angular resolution of the human eye (regard as PPD=60 [2]), the diameter of PSF can be approximated as function:

$$\text{diameter} \approx 2 \cdot \text{distance} \cdot \tan\left(\frac{1}{2 \cdot \text{PPD}}\right)$$

Then, we tried different distribution and believe that Gaussian distribution is closer to the final visual effect.

We first simulate the image based on the analysis. Firstly, according to the physical model, calculate the spot image of the pixel passing through the lens. Then, set the PSF based on the human eye's resolution limit and observation distance. Then perform convolution operation on the image, and simulate the final visual effect image seen by the human eye.

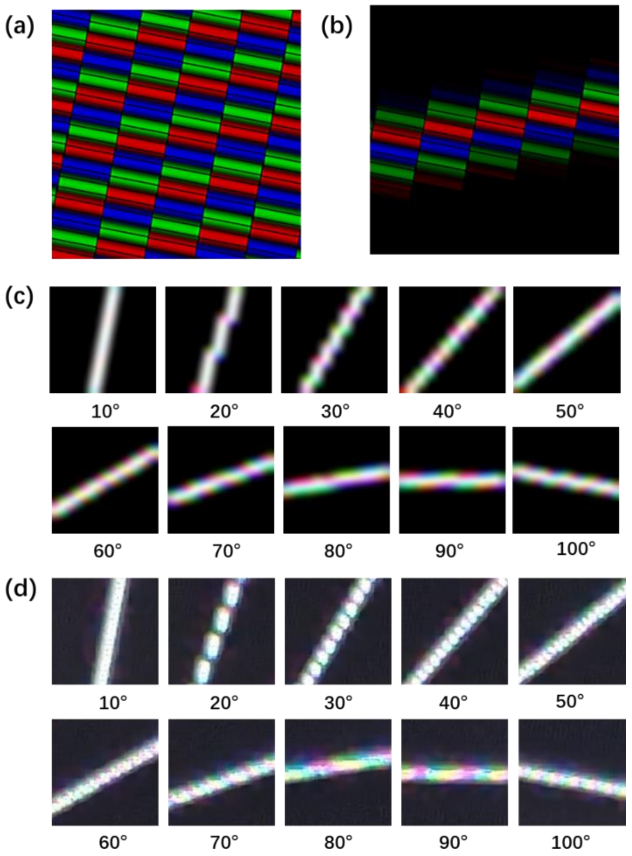


Figure 5 The severity of sparkle is related to the arrangement of RGB light spot. (a) The arrangement of the

light spot of 3D display. (b) The illuminated pixels when drawing a 80° line. (c) The sparkle image when drawing a white line from 0°~90° on the 3D display. (d) Photos we actually taken, the angle is same as simulation.

Through this method, we simulated the sparkles generated by white lines from different angles in a 3D image, calculated their color fluctuations, and obtained the relationship between angle and color difference. The result shows the sparkle is closely related to the arrangement of the RGB spot on the lens. When the line is parallel to the arrangement direction of monochrome light spot, both sides of the line will experience dispersion and irregular distribution on a large scale. The sparkle becomes more serious.

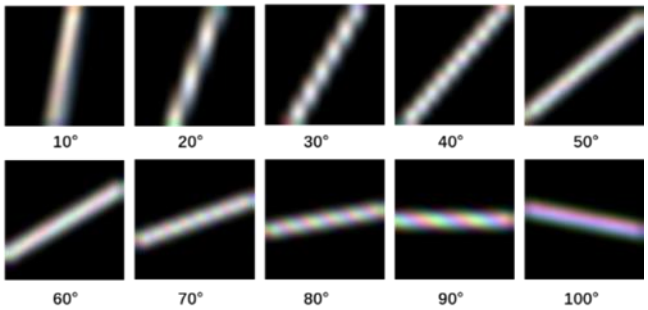


Figure 6 Optimize the sparkle to the best by change pitch and tilt angle of lenticular lens through simulation.

Then, we change the pitch and tilt angle of the lens in different parameters, to make part of the frequency of light spots in the same color lower. We draw the lines again in the same way. Compared to the irregular dispersion distribution at both sides of the line, different colors are now uniformly distributed inside the white line. When we see the image from a large distance, they will mix evenly into white, so that it is difficult for the human eyes to distinguish them.

Improvement:

The quality of 3D image can be improved mainly from two aspects: lens design and content assignment. Due to the high sensitivity of the human eye to the low-frequency parts of images. When designing a 3D lens, we try to minimize the low-frequency part of the RGB image arrangement on the lens, which can reduce the difficulty of processing 3D content in the later stage. The best arrangement ways is real RGB (shown in Figure 6). At this moment, no matter what angle we look at the 3D display, the alignment of the spot are always arranged in the pattern of real RGB. So we can assign values to the 3D display in the same way as a regular LCD. It greatly reduces the processing difficulty of the algorithm.

We can further optimize image quality in terms of algorithm. Due to the fact that the sparkle is often related to under-sampling, we believe that anti-aliasing methods can be used to handle sparkles in 3D images. Analogous to mainstream oversampling anti-aliasing methods, before assigning values to 3D images, we first oversample the 3D content and calculate the average grayscale of surrounding n*n pixels of the sampling point before assigning values. The following figures shows the anti-sparkle effect corresponding to different n values (there are 5 sub-pixels under the simulated lens here). The anti-aliasing effect of 5x5 is already obvious. It can be seen that when the number of samples required for anti-aliasing is equivalent to the number of sub pixels under the lens, the anti-aliasing effect is very effective.

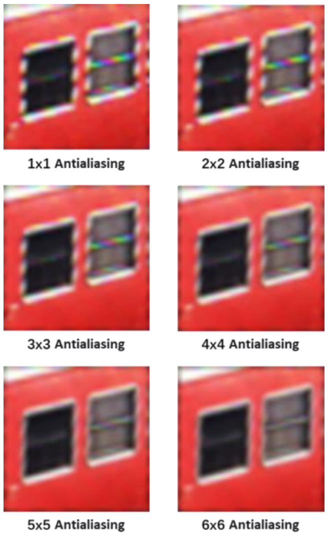


Figure 7 Improvement of anti-sparkle.

Conclusion

In this work, we have analyzed the causes of spark from both display and 3D content perspectives. We have proven its mechanism by simulation, analyzed its impact on the effect of display, and proposed a solution to overcome its limitations. The work presented in this paper may lay a basis for reducing sparkle in 3D display and improving the performance of this technology, to facilitate its application.

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