Commercial Implementation of Large Multi-Layer Displays

YuTang Tsai*, JiaLong Wu*, KunCheng Tien*, LiangYen Liu*, ChiaHao Wu*

*** Technology Group, AUO Corporation, Science Park, Hsin-Chu 30078, Taiwan, R.O.C.**

Abstract

Multi-layer displays (MLD) integrated with transparent micro LED in the front layer was proposed and studied. This research highlights the potential of MLD to deliver immersive, glasses-free 3D experiences via optimized optical designs that reduce moiré interference and enhance color synchronization across layers. MLD can be applied in various domains, including education and entertainment.

Author Keywords

Micro LED; transparent display; image quality; MLD; multi-layer display; 3D image

1. Introduction

The development of display technology largely revolves around the pursuit of presenting images that convincingly mimic natural realism to the viewer. Traditional 2D display technologies have made significant strides in achieving high resolution, full color, high contrast, and wide viewing angles; however, they still fall short in effectively delivering an immersive three-dimensional (3D) experience that fully engages human perceptual capabilities. The inability of conventional two-dimensional displays to convey depth information severely limits our understanding of the complexities of the real world. It is noteworthy that approximately 50% of the brain's processing capacity is dedicated to visual information [1]. An ideal display should function as a "window to the world," providing all necessary depth cues to create the illusion of a genuine 3D environment for the audience. The human brain utilizes a synergistic combination of physical depth cues—including accommodation, convergence, motion parallax, and binocular disparity—as well as psychological depth cues such as linear perspective, occlusion, shading, texture, and prior knowledge. In recent years, there has been a surge of interest in augmented reality (AR) and virtual reality (VR) devices, which several companies have begun commercializing.

The demand for increasingly realistic 3D experiences among consumers continues to grow; however, conventional 3D display technologies face significant challenges in effectively presenting stereoscopic images [1, 6-9]. A critical barrier is that viewers often need to wear special glasses or adhere to specific viewing distances and angles, which considerably diminishes the overall viewing experience. Furthermore, prolonged use of these displays can provoke discomfort, characterized by symptoms associated with 3D viewing, such as dizziness or eye strain. To address these issues, multilayer display (MLD) technology has been proposed, which enhances the realism and quality of stereoscopic images by simultaneously presenting all content at varying depths. This innovation allows viewers to enjoy rich content for extended periods and from angles, eliminating the need for glasses or other devices.

2. Transparent Display Technologies Used in Multi-Layer Display

Traditional naked-eye 3D technology often results in dizziness due to the Vergence-Accommodation Conflict (VAC); in contrast, multi-layer display technology provides a genuine depth 3D experience that substantially diminishes the risk of inducing dizziness, as shown in Figure 1. The integration of multi-layer display enables each display layer to independently present images at different depths, allowing these images to be overlaid and creating a spatial relationship between objects as illustrated in Figure 1, thereby generating a more immersive and distinct three-dimensional visual impact. Key features include the application of multi-layer panels to enhance depth and stereoscopic effects through the stacking of multiple transparent or semi-transparent display panels, each capable of presenting clear images, which enriches the overall display experience and resolution while ensuring high image quality. This technology is focused on delivering realistic depth perception, enhancing the immersive experience for viewers, and significantly amplifying the 3D effect to make the stereoscopic visuals more captivating. Additionally, image overlay and composition techniques, such as shadow enhancement, allow for the combination of images from different layers to form composite visual effects, thus enabling the simultaneous presentation of multiple scenes or content and providing viewers with a more flexible and unrestricted viewing experience without the need for special glasses.

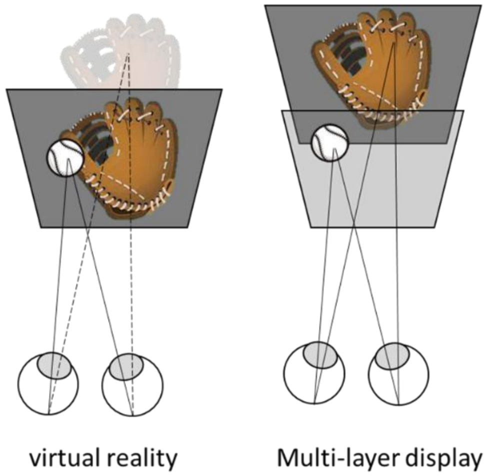

Figure 1. Schematic of traditional naked-eye 3D technology vs. multi-layer display (MLD) technology.

Traditional liquid crystal-based multi-layer displays consist of multiple liquid crystal panels coupled with polarizing films. By carefully controlling these display panels, it is possible to approximate the reproduction of light fields in three-dimensional scenes, encompassing spatial, directional, and luminous information, thereby enabling glasses-free stereoscopic vision from various viewpoints. However, in LCD based multi-layer displays, each color channel—specifically red, green, and blue—is facilitated by independent liquid crystal filters; unfortunately, the transmission spectra of these filters may overlap, resulting in a phenomenon known as color-channel crosstalk, where activation of one channel can inadvertently permit some transmission of colors from the other channels, causing color distortion [2]. This crosstalk is a significant concern when utilizing dual-layer LCDs, particularly since the design of the

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color filters in multi-layer displays (MLDs) is often not optimized for dual-layer configurations, which can exacerbate inter-channel crosstalk and negatively impact overall image quality. Due to the overlapping transmission spectra, color mixing can also occur in grayscale regions, introducing visual artifacts in the displayed images. The presence of such crosstalk increases the reconstruction error of the display, making the issue more pronounced when optimization is attempted for specific visual effects. Addressing this crosstalk through thoughtful design and optimization is crucial; potential solutions may include the development of more precise color filters or the implementation of advanced optimization algorithms aimed at minimizing crosstalk. Therefore, commercial applications must prioritize advancements in this area to enhance display quality and color accuracy.

The aforementioned technical challenges have persisted for years, hindering the commercial development prospects of multi-layer displays. However, with ongoing advancements in display technology, self-emissive display solutions, including organic light-emitting diodes (OLED) and micro LED technologies, have matured and become mainstream options in the market. By integrating self-emissive displays into multi-layer configurations to replace the traditional LCD as the front layer of the MLD, these identified issues can be effectively resolved, allowing light emitted from the rear display to pass solely through the transparent apertures of the front display without any color crosstalk affecting the rendering of the background image. Moreover, self-emissive transparent displays do not require polarizers, which significantly enhances the luminous output of the background image.

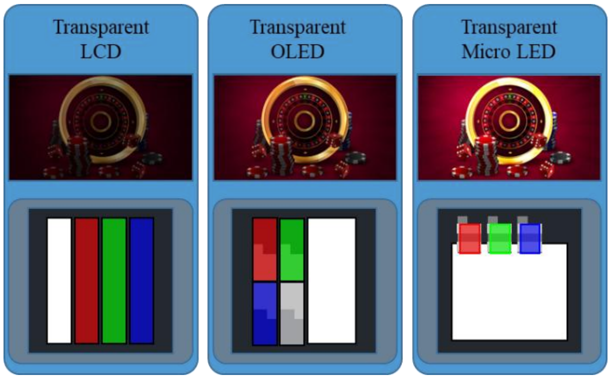

Figure 2. Visual performances and conceptual pixel layouts of three transparent displays applied in the front layer of MLD.

Figure 2 illustrates the comparative effects of three types of transparent displays used in the front layer of the multi-layer display (MLD) system. The upper half of Figure 2 highlights the differences in visual performance among various display technologies utilized in the front layer of multilayer displays (MLD). It shows that the integration of transparent LCDs in the front layer results in the lowest overall transmission rate among the three options, necessitating extremely high backlight brightness to achieve satisfactory luminosity levels. The lower half of Figure 2 conveys schematic representations of the pixel layouts associated with these different transparent display technologies. The high current tolerance of micro LED technology can provide much higher brightness levels than OLED technology. Therefore, the non-transparent area of micro LED would be much smaller than OLED. Highest transparent area ratio of the pixel layout can be obtained by micro LED technology, which enables most vivid background images simultaneously. Not only brighter front images but also brighter background images are provided by micro LED technology, compared to OLED technology.

3. Implementation of High-Performance Multi-Layer Display

The MLD structure with the front layer of transparent micro LED display and the rear layer of LCD display was proposed in this work, where the transparent micro LED display achieves brightness levels exceeding 600 nits and contrast ratio of up to 1,000,000:1. Compared to conventional 3D displays, this approach remarkably improves image vibrancy and clarity, thereby providing users with an exceptional visual experience. In terms of transparency, transparent micro LED technology enables displays to achieve over 65% light transmittance, far exceeding traditional LCDs (with transmittance <10%) and OLED technologies (with transmittance <45%). This feature allows users to enjoy a more realistic stereoscopic effect while maintaining clear visibility of the background image, enhancing the overall natural visual experience. However, to achieve efficient 3D display quality in multi-layer displays, effective suppression of optical interference is essential. Optical interference between components (such as moiré patterns) can degrade image quality [3]. Moiré interference phenomena in the MLD structure arise from the specific arrangements of pixels within the display panels. When two patterns with similar periodic structures are placed in close proximity, moiré interference occurs, resulting in unique patterns whose frequency and amplitude are influenced by the relative alignment of the pixel arrangements in each layer. Within the MLD framework, the interaction between the pixel arrangements in the front and rear layers can lead to the emergence of moiré interference patterns. If viewers perceive these patterns, it may lead to visual disturbances. Research has indicated that the application of optical diffusers can mitigate this interference effect. Optical diffusers are strategically positioned above the rear-layer display to attenuate high-frequency components. Through light scattering, diffusers promote a more uniform light distribution, thus reducing the visibility of interference patterns. Specifically, they serve to diminish high-frequency elements, blur fine details in displayed patterns, and reduce interference effects in composite images. Therefore, AUO's proprietary Advanced Reflectionless Technology (A.R.T.) LCD technology has been utilized in this MLD architecture to reduce light reflections between the front and rear display layers, enhance transparency, and minimize optical interference. The A.R.T. technology is acclaimed for its excellent anti-glare and anti-reflective properties in bright environments, thereby improving the overall viewing experience of the MLD. It improves the display's effectiveness across varied environmental conditions, which is particularly critical for displays intended for outdoor use or in brightly lit indoor environments. In addition, color consistency within MLD is paramount. The human eye simultaneously receives visual information from the displays, contributing to the perception of a three-dimensional effect. Accordingly, the colors presented by both displays must be closely aligned to achieve this effect. Such color alignment is necessary to prevent noticeable discrepancies when displaying the same hue, as these inconsistencies could adversely impact the quality of the stereoscopic image. To achieve consistent coloration through MLD, it is essential to accurately calibrate each layer display utilizing specialized calibration techniques and digital signal processing. The measurement and calibration of the color characteristics of each display is critical. Furthermore, synchronizing the grayscale output between the front-layer and rear-layer displays is vital for ensuring a seamless transition across the entire image. The differences in color perception of MLD by the human eye are primarily attributed to two factors. First, the inherent variations in the performance of the primary colors (red, green, and blue) arise from the distinct display technologies utilized in the front micro LED and the rear LCD. Second, the background images displayed by the rear display are influenced by the transmission spectral characteristics of the front display, often resulting in a yellowish tint. Given that micro LED technology offers a wide color gamut and high brightness, it allows for greater flexibility in adjustment. Therefore, the color of the LCD light passing through the front micro LED should be set to the target white point for color alignment. Subsequently, adjustments should be made to the output colors of the Micro LED to ensure consistency in the overall white point. This method will achieve a close match in the perceived white chromaticities from both displays, thereby enhancing the overall viewing experience.

Figure 3. Content production includes 3D modeling, layering for depth, shadowing, rendering, and color mapping.

In Figure 3, content production encompasses several stages, including 3D modeling, grayscale modeling, layering based on object emphasis and depth information, shadowing, rendering to minimize discontinuities between layers, and color mapping. The process begins with the creation of a simple 3D object to establish the 3D structure, followed by the introduction of a light source to enhance the visual effects. Subsequently, layered images are produced by integrating 2D images, while correcting seams between the upper and lower layers to prevent visual discontinuities. Unlike traditional 2D displays, MLD enhance depth perception by creating the illusion that objects on the front layer are closer than those on the rear layer. This configuration enables the relative movement of objects across different layers as the viewer alters their head position. Depth perception is influenced by both psychological and physiological cues; psychological cues include factors such as perspective, atmospheric effects, and occlusion, while physiological cues are primarily based on binocular disparity and convergence [4-5]. These depth cues assist observers in discerning the relative distances and positions of objects. Within the framework of multi-layer display technology, rendering techniques are applied to enhance the perception of 3D depth. Initially, significant objects are emphasized by placing them on different layers, typically the front layer, to enhance their visibility through color contrast. For example, using lighter colors for foreground objects against a darker background prevents their blending into the background. Subsequently, the scene can be segmented based on the Z-values (depth information) of the objects, rendering closer objects in the front layer and more distant objects in the rear layer. This technique allows for the representation of depth changes in response to head movements. In the gradient technique, static object layers are rendered with gradients applied at the boundaries between the front and rear layers to further enhance depth perception. Additionally, during the transition between layers, depth perception can be enhanced by adjusting the rendering proportions of objects on each layer, making higher-rendered layers appear closer to the viewer. Furthermore, grayscale depth maps can be used to adjust the display positions of individual pixels across different layers, effectively determining which objects reside in the front or rear layer. Figure 4 illustrates the presentation of 3D images from various angles. In the depicted objects, a high-quality 3D visual experience is achieved through depth Z-value layering, the application of shadowing, rendering techniques to minimize discontinuities between layers, and effective color mapping. In summary, multi-layer display technology holds significant potential for enhancing 3D visual experiences, and the effective application of rendering techniques can substantially improve viewers' depth perception by controlling the spatial relationships and layering of displayed objects.

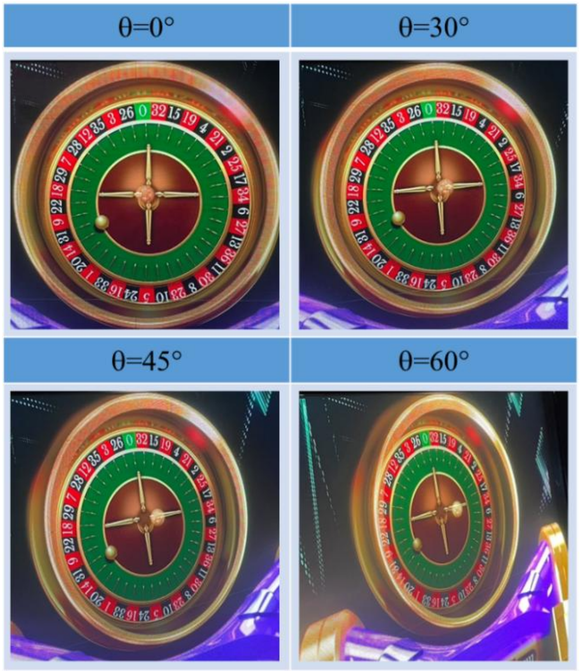

Figure 4. 3D images presentation from various angles using depth layering and shadowing techniques

After content production, animation output can be initiated by precisely positioning the upper and lower images at their respective pixel locations. It is important to note that the digital spatial coordinates of the stitched display differ from the visual positions perceived by the human eye within the physical space of the multi-layer display (MLD). At this stage, attention must be given to image signal synchronization and hardware optimization issues. Multi-layer displays (MLD) utilize a coordinated pairing of two displays to create a cohesive visual effect. To effectively present dynamic images, the outputs on both displays must be accurately synchronized to ensure the overall quality of the stereoscopic experience. A common approach involves using graphics cards that support multi-display technology, such as NVIDIA's Surround and Mosaic technologies or AMD's Eyefinity, which amalgamate the outputs of the two displays into a single screen. This method positions the corresponding images based on the display areas of the two screens to achieve synchronization. However, this approach places specific demands on the playback equipment and requires additional software configuration, thereby increasing the complexity of the MLD system. To enhance the commercial viability of MLD technology, dedicated equipment capable of managing image signals is essential, facilitating seamless operation under standard conditions. Currently, AUO has developed specialized equipment for processing MLD image data. This device accepts image inputs at specific resolutions and subsequently allocates the necessary images for each display prior to transmission. Users need only to provide image data at the predetermined resolution, and the system accurately positions the relevant images according to the MLD display area, achieving synchronized stereoscopic image information without the need for additional software configuration.

Figure 5. The 30” MLD panel uses transparent Micro LED and A.R.T. LCD to provide a true 3D experience for multiple viewers without wearables, even at varying distances and angles.

4. Discussion & conclusion

The 30-inch true stereoscopic display represents a notable advancement in display technology, aimed at delivering an immersive and realistic visual experience. Utilizing a multi-layer display system, each layer independently presents images at different depths, creating a rich stereoscopic effect. By integrating A.R.T. LCD technology with transparent Micro LED, this display provides autostereoscopic capabilities that eliminate the need for special glasses, enhancing possibilities for virtual reality (VR) experiences. Users can simultaneously engage with multiple layers of virtual or augmented content, increasing both immersion and realism. A.R.T. LCD effectively minimizes reflections while providing a clear virtual background, which contributes to a more authentic environment. The high transparency of the transparent Micro LED allows users to perceive both virtual content and their surroundings, overcoming limitations typically found in traditional displays. In education, this technology enables the simultaneous presentation of multi-layered content, such as anatomical models and geographical representations, which enhances the learning experience. Students can interact through touch or gesture controls to explore different layers, fostering a more engaging educational environment. In entertainment and gaming, the display provides captivating visual effects and interactivity, with the Micro LED technology maintaining excellent brightness and contrast under various lighting conditions. Enhanced interactivity allows users to switch between content layers via touch, aligning with modern demands for intuitive operation. The display's versatility extends beyond VR, with applications in augmented reality, education, art, and entertainment, making it a multifaceted solution for diverse scenarios. Overall, this 30-inch true stereoscopic display integrates cutting-edge technology and original design, positioning itself as a unique product that sets a new standard in the evolution of display technology.

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