31.4: Direct View and Projection Switchable Mobile Display

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Abstract
The function of mobile phone becomes more versatile as a personal assistant. In order to make display device optimized for different function of the mobile phone, this paper proposes a display device which can be switched among 2D direct view, 3D direct view and projection modes while using single liquid crystal(LC) panel as image source. The device features a highly collimated backlight unit and polymer dispersed liquid crystal(PDLC) diffuser at the back of the LC panel, and a switchable lenticular array as well as a stretchable projection lens in front. The ray tracing simulation has shown well controlled light path of the backlight module and sufficient image quality of the projection lens while maintaining the compactness of the device for mobile application.

1. Introduction
The function of mobile phone nowadays is not limited for speech communication as for its original purpose and becomes more versatile as a personal assistant and/or entertainment unit. The integration of camera imaging, PDA, GPS and video game has already been popular in the market. Integration of TV and internet access etc will gain more attention in the near future. The display unit plays the key role as the human interface for those different function and application of the mobile phone. However, different application requests different specification of the display unit with the consideration on effectiveness and efficiency. Therefore, quite a few integrated or switchable display unit have been proposed, including 2D/3D switchable display[1] and pico projector embedded into a handset with a direct view panel of its own[2] etc. In this paper, a versatile display unit which can be switched among 2D direct view, 3D direct view and projection modes while using single LC panel as the image source has been proposed. The form factor is also taken into consideration in evaluating the feasibility of the architecture in order to ensure its availability as a mobile display unit.

2. Switchable display configuration
The architecture of the display unit being proposed is shown in Figure 1, which looks similar to a folding mobile phone with the image source panel and illumination backlight module in the bottom plate, and a projection lens in the top plate. The image source is a traditional liquid crystal panel with a polymer dispersed liquid crystal(PDLC) diffuser[3] underneath in between the backlight module and the LC panel. The backlight module needs to have the emerging light from the top surface as collimated as possible. A switchable lenticular array[4] or parallax barrier[5] is attached onto the top surface of the LC panel. The projection lens in the top plate is a stretchable one, similar to several camera lenses, which stretch out only when being used.

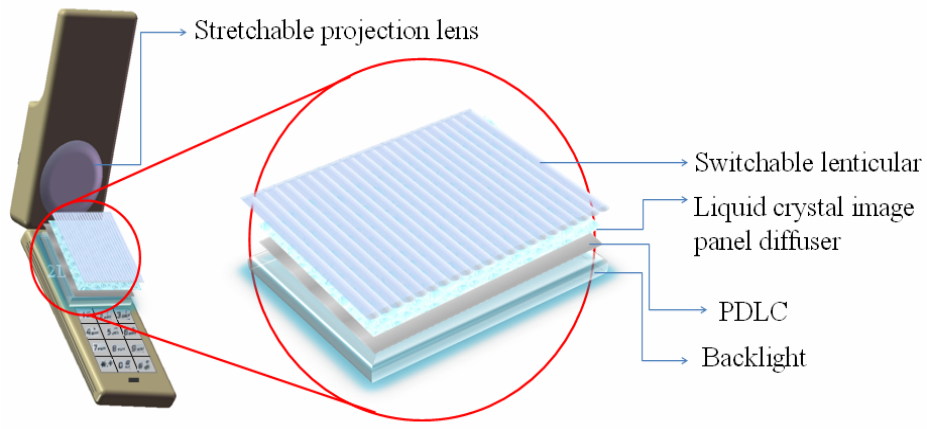

Figure 1 Configuration of the proposed three-in-one hybrid display unit

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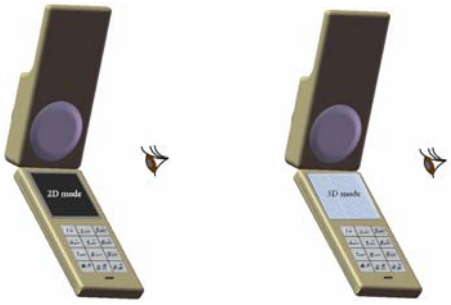
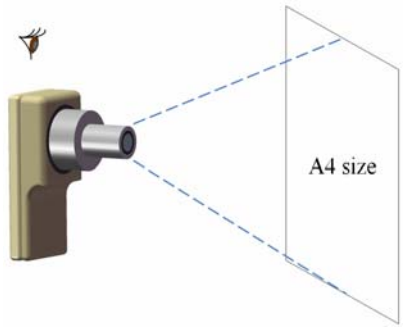
Three different operation modes of the display unit, namely 2D direct view, 3D direct view and projection modes, are illustrated in Figure 2. For 2D direct view as in Figure 2(a), the cover plate is flipped over, the PDLC is off and becomes highly diffusive, and the switchable lenticular array is off to behave like a simple transparent plate. In 3D direct view mode as shown in Figure 2(b), the cover plate is flipped over, the PDLC is on to become a simple transparent film, the switchable lenticular array is on so as to direct light towards different viewing direction for different group of pixel and become a spatial multiplexed autostereoscopic 3D display. The projection mode requests to close the cover plate and stretch the projection lens element, as shown in Figure 2(c). In this mode, the PDLC is on to make the illumination highly collimated, and the switchable lenticular array should be disabled.



(a) **(b)**

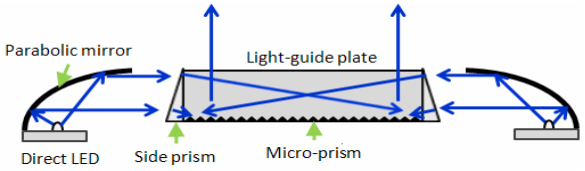


(c)

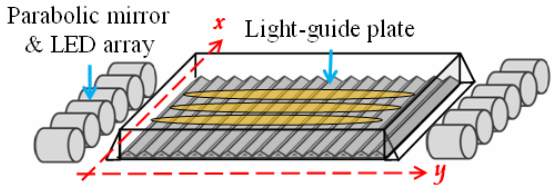
Figure.2 Operation mode of hybrid display unit
(a) 2D (b) 3D (c) Projection mode

3. High collimation backlight module

The above mentioned concept is clearly feasible based on the currently available technology, and the key issues become the form factor and maintaining efficiency in switching between direct view and projection mode. A highly collimated backlight is desired for projection mode, while it can be diffused in direct view mode by a PDLC diffuser at off state. Figure 3 shows the top view and bird's eye view of the high collimation backlight module using LEDs as the light source. The LEDs located at the side edge of the light guide are firstly collimated by a parabolic reflector, one for each LED. Micro-scale prism structure is patterned on the bottom surface of the light guide to make the emerging light from the top surface confined within a small cone angle. Figure 4(a) and (b) show the illuminance distribution over the light guide surface and the angular profile of emerging light respectively from the simulation result of ray tracing using Light Tools. The uniformity reaches 70% and the angular divergence is less than 5° measured at half intensity. The total thickness of the backlight light module is 15mm.

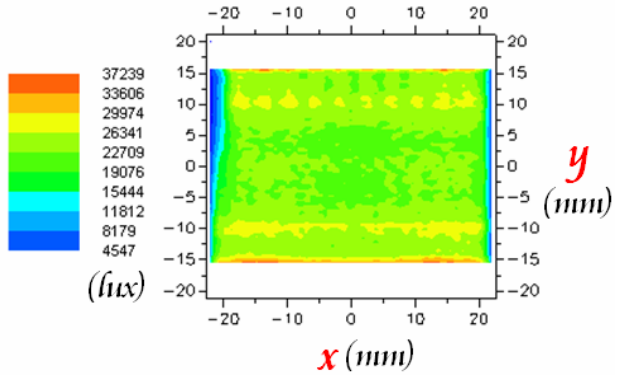


(a)

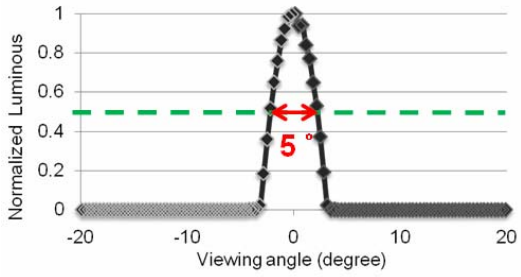


(b)

Figure 3 Configuration of high collimation backlight module(a) Side view (b)Bird's eye view



(a)



(b)

Figure 4 (a)Illuminace distribution (b)Angular profile of emerging light from backlight module Stretchable projection lens

4. Stretchable projection lens

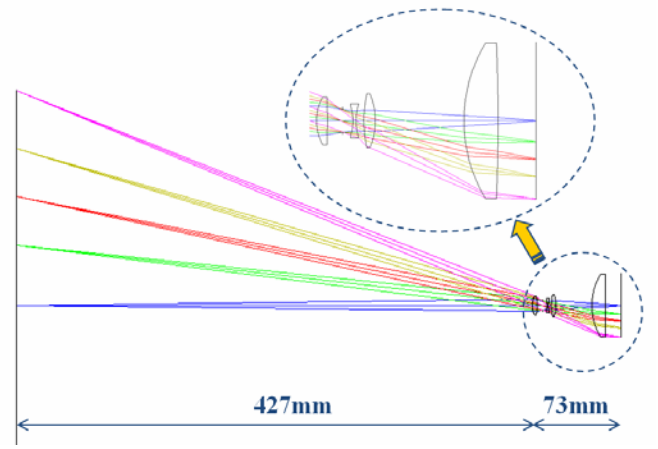
The projection lens needs to provide good quality image while having compact form factor. The trade-off can be resolved with a stretchable lens module as what has been adapted in several compact digital cameras. Figure 5(a) show the layout and light path of the projection lens at stretching condition. All the four lenses are spherical plastic lens. Table 1 lists the parameters of projection lens which include radius, thickness and the lens material. PMMA is the only material used in this design because of cost consideration. The panel size on the right end of the light path has a diagonal size of 1.96 inches and an aspect ratio of 4:3. The pixel size is 0.1245mm, which corresponds to spatial frequency of 4.0 lp/mm. Figure 5(b) shows the MTF of the projection lens, which indicates a MTF of 50% at 5 lp/mm. One major feature of the projection lens is telecentricity at the panel side with a ray cone of 5° half angle. Accompanying with the high collimation light guide, it makes the best use of the energy from the light source in projection mode. The other feature of the projection lens is the compact size of lens element stretching far away from the image source, which makes the display unit mechanically stable in projection mode operation. The total track of the light path in Figure 5(a) is 500mm, and the total thickness of the lens elements is 19.9mm, which will be roughly the thickness of the cover plate containing projection lens elements. The project image size is 180mm*135mm, roughly A4 size, with a throw distance of 427mm.

Table 1 the list of radius, thickness and material for the projection lens

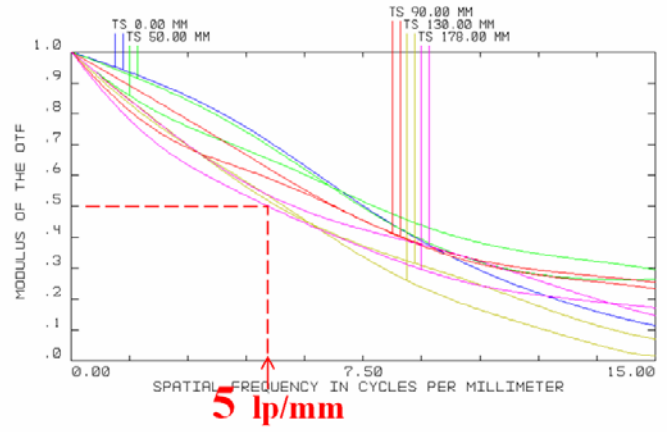
	Radius	Thickness	Glass
Object	Infinity	426.7	
1	16.5	3.6	PMMA
2	-465.4	5	
Stop	Infinity	3.5	
4	-16.2	1.1	PMMA
5	19	2.6	
6	41.3	3.8	PMMA
7	-23.7	29.6	
8	50.5	11.4	PMMA
9	-656.9	12.6	
Image	Infinity		

5. Conclusion

A three-in-one hybrid display unit using single image source panel has been proposed as the visual interface for mobile device. The display provides switchable function among 2D direct view, 3D direct view and projection. The major feature of the hardware is a highly collimated backlight module and a stretchable projection lens. Ray tracing simulation has shown sufficient performance of both modules and the feasibility of the proposed display architecture.



(a)



(b)

Figure 5. (a) Light path and layout (b) MTF of projection lens at stretching condition

6. References

[1] K. J. Kim, H. Kang, " Development of a 42-in. 2-D/3-D switchable display using multi-view technology for public-information-display applications," in *SID 15/11*, 2007, pp.899-903

[2] Denis Darmon, John R. McNeil, and Mark A. Handschy " LED-Illuminated Pico Projector Architectures," *J. Appl. Phys. Lett. Vol.48*, pp.269-271,1986.

[3] W. Doane, N.A. Vaz, B.-G. Wu, S. Zumer, " Field controlled light scattering from nematic microdroplets," *Prodeedings of SID*, 2008,pp.1070-1073.

[4] S.T. de Zwart, " A 20" Switchable Auto-Stereoscopic 2D/3D Display," *Prodeedings of IDW'04*,pp.1459-1460.

[5] Byoungho Lee, Heejin Choi, Joohwan Kim, Yunhee Kim, and Seong-Woo Cho, " Status and Prospects of Autostereoscopic 3D Display Technologies," *Prodeedings of IEEE*, pp. 354-355, 2007.