Invited Paper

Liquid Crystal Lens Array for 3D Display and 3D Air-touch

Yi-Pai Huang, Tai-Hsieng Jen, Yu-Cheng Chang, Guo-Zhen Wang
Po-Yuan Shieh, Chi-Wei Chen, and Lin-Yao Liao

Department of Photonics/Display Institute,
National Chiao-Tung University, 1001 TaShud Rd, HsinChu, Taiwan

ABSTRACT

A low driving voltage with fast response LC-lens by using high resistance material was developed. By implementing the LC-lens as an array structure, it can be adaptively used for multi-function of 3D displays. Furthermore, by combining with coded optical barrier with embedded optical sensors, it can yield 3D air-touch function.

Keywords: Liquid Crystal lens Array, 3D Display, 3D Air-touch, 3D interaction

INTRODUCTION

Recently, many types of 2D/3D switchable auto-stereoscopic displays are proposed in order to keep the 2D resolution [1-2]. The LC devices can perform the switchable parallax barrier and lenticular lens to enable 3D displays to switch between 2D and 3D modes. However, the 2D/3D switchable function is insufficient for current portable d devices having auto screen rotate function, such as smart phones and tablet PCs, because the current 2D/3D switchable function is unable to achieve the 3D rotation due to disabling to change the arrangement direction of parallax barrier or lenticular lens. Additionally, those technologies cannot display full-resolution 2D contents and 3D contents at the same time, because these LC devices cannot locally perform parallax barrier or lenticular lens. The resolution of 2D contents will be reduced by at least half resolution depending on the number of views of the 3D display. Thus, we need an electrically switchable device having the 2D/3D switchable, dual-oriented 3D and partial 2D/3D switchable functions for current portable devices, as shown in Fig.1.

For 3D Display, in this paper, we propose a multifunctional LC lens array that enabled auto-stereoscopic displays to achieve above three functions. Additionally, the design of LC lens devices is based on a compact size and easy-fabrication without any curved surface. Thus, the fabrication can be compatible with the fabrication of the current well-developed LCD industry and make auto-stereoscopic displays have more functions and applications used in our daily life.

Beyond the 3D display, for further "touch" on the virtual 3D object and interact with it; we proposed a coded optical barrier on embedded photo sensor array. By combining with the LC-lens array above the display screen, the "3D air-touch" technology can be realized.

(a) (b)

Fig. 1 Schematic plot of adaptive LC-lens Array for (a) multi-functional 3D display, and (b) 3D air-touch function.

2013 International Conference on Optical Instruments and Technology: Optical Systems and Modern Optoelectronic Instruments, edited by Yongtian Wang, Xiaocong Yuan, Yunlong Sheng, Kimio Tatsuno, Proc. of SPIE Vol. 9042, 90420F · © 2013 SPIE · CCC code: 0277-786X/13/$18 · doi: 10.1117/12.2049181

DUAL-ORIENTED 3D AND PARTIAL 2D/3D SWITCHABLE DISPLAY

1.1 Dual-oriented 3D switchable function

In order to achieve dual-oriented 3D switchable function, top electrodes and bottom electrodes must have different orientations, as shown in Fig.2. When all bottom electrodes are connected to ground and top electrodes are driven by interlaced voltage, VD and ground, LC lens arrange in the horizontal orientation. Due to the same driving voltage, the bottom electrodes become a full electrode with ground voltage. When bottom electrodes are driven by interlaced voltage, LC lens switch to the vertical orientation.

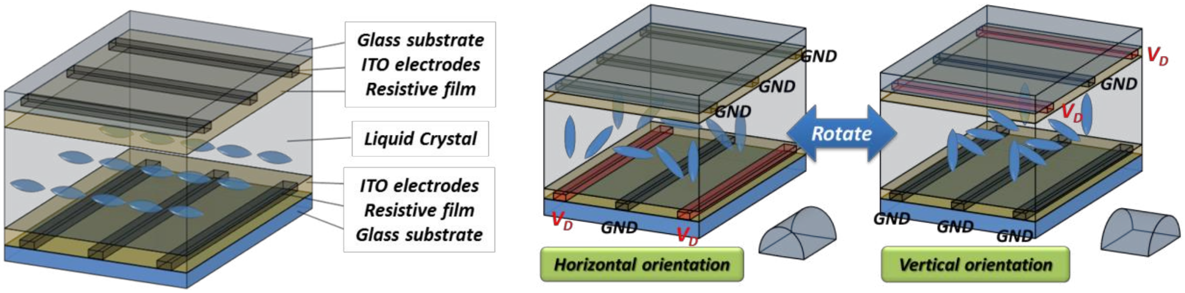


Fig. 2 Sketch of the structure of multi-functional liquid crystal lens array, and driving method for dual-oriented 3D switchable function.

1.2 Partial 2D/3D switchable function

The driving method partial 2D/3D switchable function is shown in Fig. 3. If we want to form the lens in the 3D region, there are no lenses in the other regions. This driving method needs three different voltages, V_{3D}, $V_{2D,\ TOP}$ and $V_{2D,\ BOT}$, which applied on the bottom electrodes in the 3D regions, the top and bottom electrodes in the 2D regions. The magnitude of $V_{2D,\ TOP}$ and $V_{2D,\ BOT}$ are higher than V_{3D}. Therefore, there is a big potential difference between the top and bottom in the 2D regions. It make the whole LC are vertical. In the 3D region, the LC distribution has a gradient orientation from vertical direction to horizontal direction to produce lens effect.

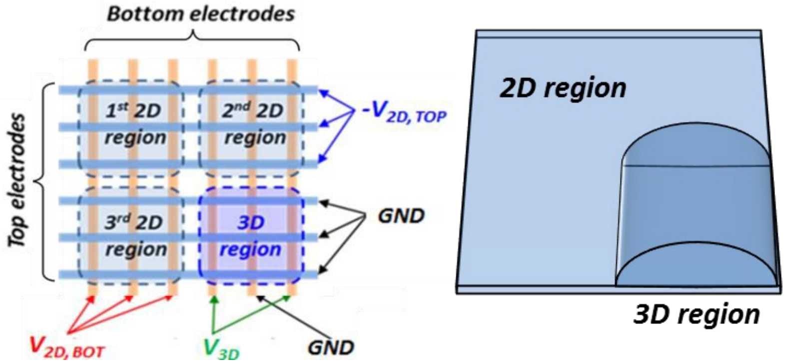


Fig. 3 Driving method of partial 2D/3D switchable function.

1.3 Experiment Results of Multi-functional 3D displays

The specification of the prototype is shown in Table 1. For dual-oriented 3D function, the driving voltages are 2Vrms. For partial 2D/3D switchable function, the driving voltages are 2Vrms for the bottom electrodes in the 3D region, 6Vrms for the bottom electrodes in the 2D region and 4Vrms for the top electrodes. The dual-oriented 3D switchable function is verified, according to the angular distributions for horizontal and vertical 3D mode, as shown in Fig. 4.

For partial 2D/3D switching, the 2D regions are divided into three regions according to the different driving conditions. The angular distributions of 2D regions are shown in Fig. 5(Left a-c). In accordance with the measured data, multifunctional LC lens array can be applied on display devices to supply the partial 2D/3D switching function. In addition, we demonstrate the partial 2D/3D auto-stereoscopic display to show the text in 2D regions and the 3D region. The camera captures the text at the viewing direction with lowest 3D crosstalk. The full resolution of the texts can be displayed in the three 2D regions, as shown in Fig. 5(Right a-c), respectively. The low resolution of the text is displayed in the 3D region, as shown in Fig. 5 (Right d). It can prove the display can actually show 2D contents with the full resolution.

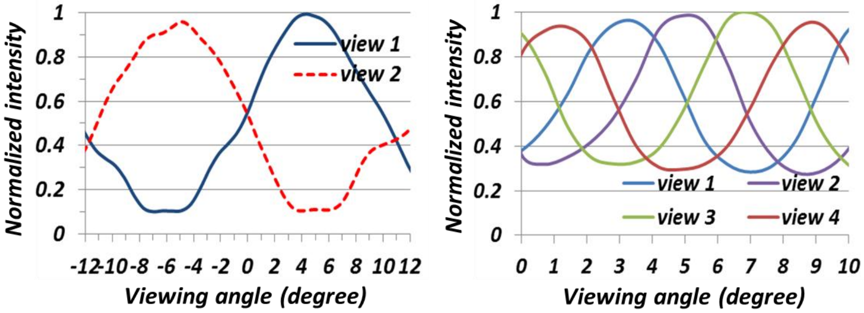


Fig. 4 Angular distributions for horizontal and vertical 3D modes.

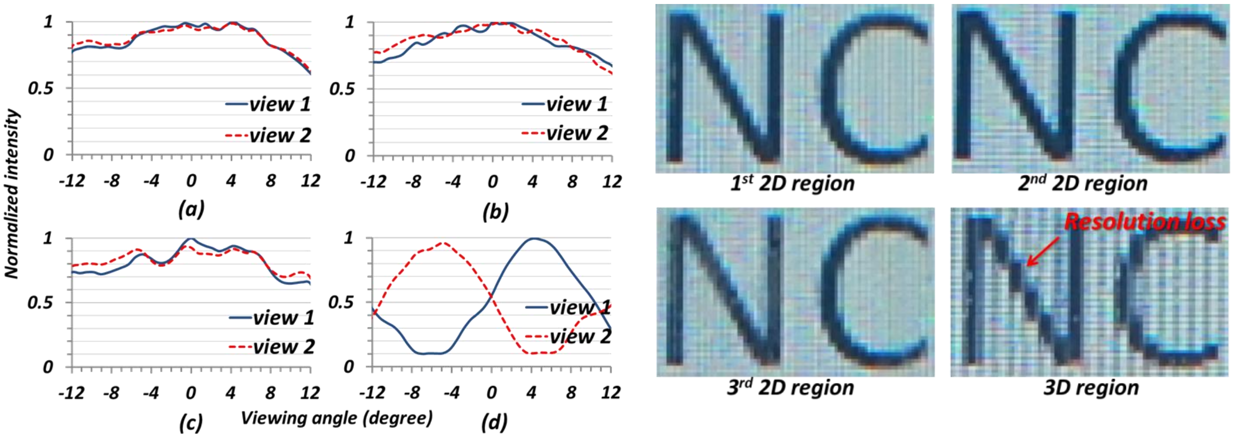


Fig. 5 Angular distributions and captured images from the prototype for partial 2D/3D switchable function in (a) first 2D, (b) second 2D, (c) third 2D and (d) 3D regions.Here is a sample illustration and caption for a multimedia file:

CODED OPTICAL BARRIER FOR 3D AIR TOUCH

1.4 Construction and Method

The present paper designed depth sensors to achieve neardistance touch. Based on traditional LC display, there are three main components. First, IR light is integrated with display backlight system, acting as touch light source. With IR light source, display image would not be affected. Second, IR photo sensor is embedded on the TFT substrate as common in-cell sensor. Third and the most distinct portion of the whole system is optical barrier. Optical barrier is located above and patterned for each pixel of photo sensor. With optical barrier on top, optical sensor becomes depth-sensitive and it will be detailed in next paragraph. Besides, depth sensors are at black matrix region, so aperture ratio would not be affected much and sensor would not be influenced by backlight system.

In depth sensor, we designed an aperture above each photo sensor, as depicted in Fig. 6. Aside from fixed pitch of LC cell (p) in the panel, all we design is displacement between the sensor and the aperture (d). More to our concept, we classified depth sensor into two types: xy-sensor and multiple z-sensors. In xy-sensor, the aperture is directly located above the photo sensor (i.e. d=0). On the other hand in z-sensor, aperture is slightly shifted with displacement (d) so that the sensor is able to capture directional light input. Nonetheless, multiple z-sensors are around the xy-sensor, and the displacement (d) of each z-sensor is different in order to sense the input at different depth (z).Moreover, as an example depicted in Fig. 6., Z1-sensor can capture strong signal while -sensor capture weak signal. Generally, captured intensity of each z-sensor is highly related to the depth (z) of input; hence a data base, which records captured intensity and known depth, is constructed for depth sensing. Finally according to the database, a continuous working range is constructed.

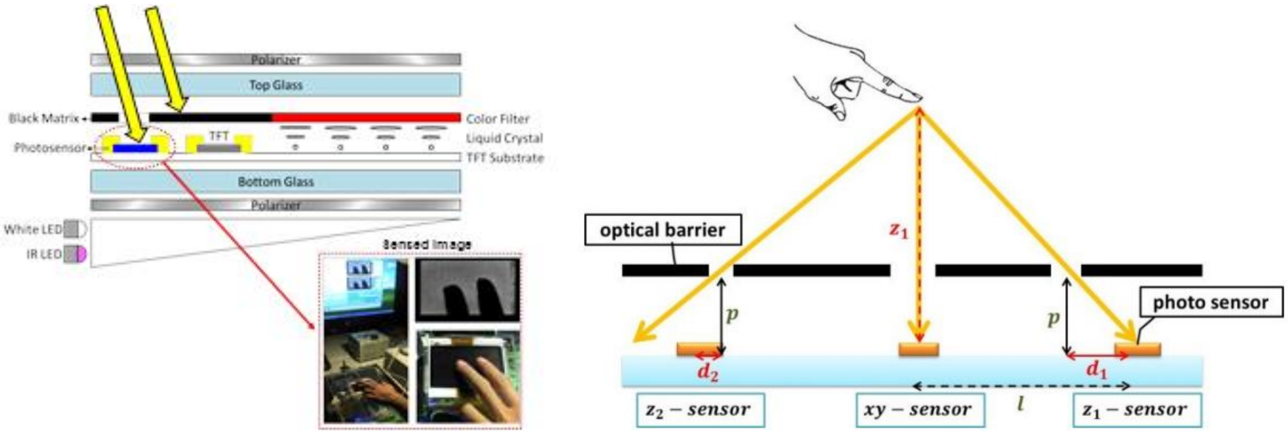


Fig. 6. Schematic structure of embedded optical sensor on TFT substrate and sensed image. Also the depth-sensing principle and system architecture.

1.5 Experiment Results of 3D Air-touch

To verify the proposed concept, our prototype was built on a 4-inch mobile auto-stereoscopic display with parallax barriers. Unfortunitly, our current prototype is not embeded coded optical barriers. Therefore, we attach the home-made mask onto the cover glass for simulating the coded optical barriers, as shown in Fig. 7. The linearity and errors at different working depth was measured. At each step, we measured the inputs 15 times; the depth response is illustrated in Fig. 8. The maximum error was less than 5 mm with average in 1mm, which shall be applicable for 3D Air-touch system.

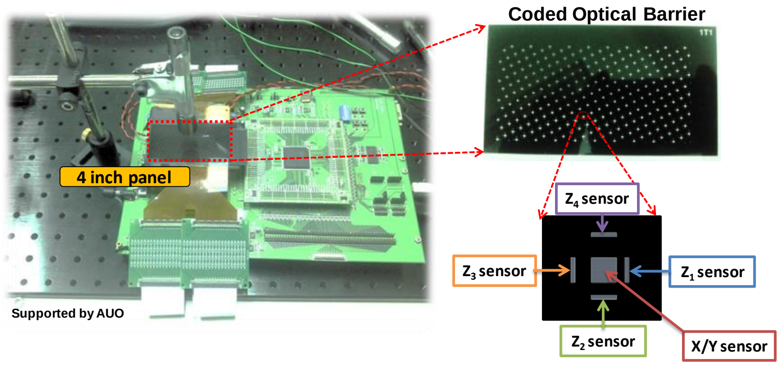


Fig. 7. Experimental platform with coded optical barriers.

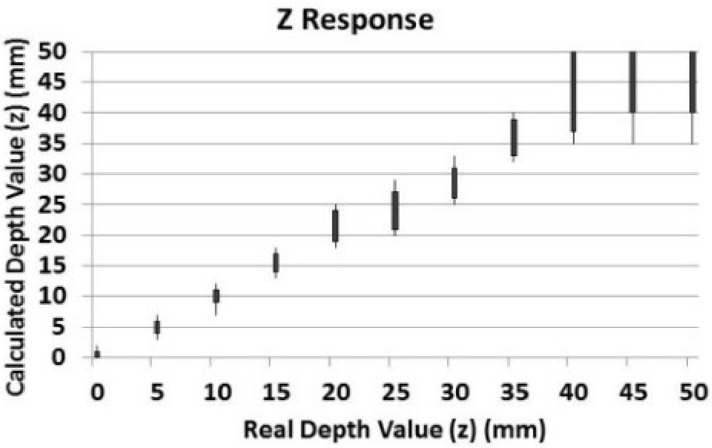
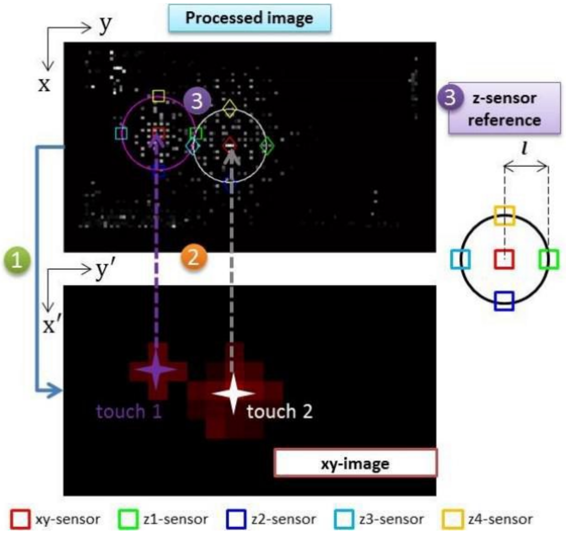
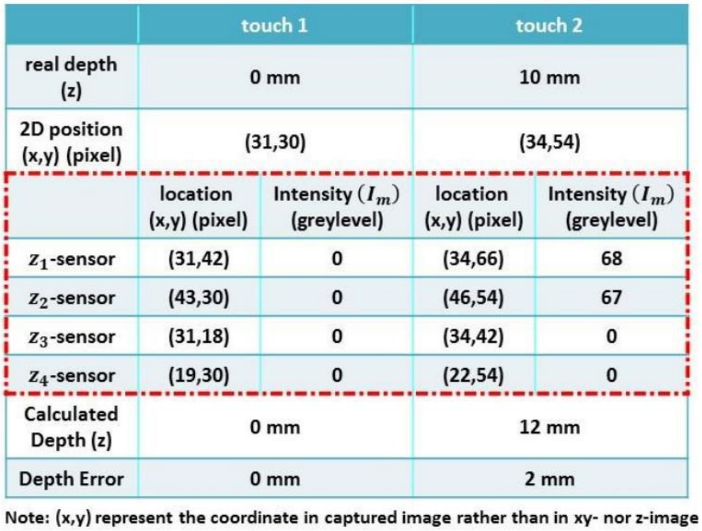


Fig. 8. . 3D sensed depth response with average error measurement.

We also clarified the feasibility of multi-touch function. An example of 2-touch points is shown in Fig. 9., two touch points were put at 0, 10 mm separately. For clear understanding, the procedure flow is narrated as followed. In the figure, the arrow 1 indicated the procedure of 2D coordinate location; xyimage was extracted from the captured image, then ISODATA clustering rendered the 2D position (x',y') of each touch points. Following, arrow 2, the locations were mapped into the original coordinate system (x,y) in captured image. In the final procedures 3 in the figure, the intensity values of z-sensors were referenced. Moreover, remind of the system architecture in Figure 2, the spacing between xy- and z-sensors is fixed (l). We only regarded and extracted (Im) at correct position, while all other valued pixels were neglected. Furthermore to the example, the detail processed data were listed in the flowing table, which included information of z-sensor reference in red dot-line square.





	touch 1		touch 2	
real depth (z)	0 mm		10 mm	
2D position (x,y) (pixel)	(31,30)		(34,54)	
	location (x,y) (pixel)	Intensity (I_m) (greylevel)	location (x,y) (pixel)	Intensity (I_m) (greylevel)
z_1-sensor	(31,42)	0	(34,66)	68
z_2-sensor	(43,30)	0	(46,54)	67
z_3-sensor	(31,18)	0	(34,42)	0
z_4-sensor	(19,30)	0	(22,54)	0
Calculated Depth (z)	0 mm		12 mm	
Depth Error	0 mm		2 mm	

Note: (x,y) represent the coordinate in captured image rather than in xy- nor z-image

Fig. 9. Example of 2 touch points and separation, and measured data of the multi-touch test.

CONCLUSIONS

We successfully achieve a dual-oriented partial 2D/3D switchable auto-stereoscopic display using multi-functional liquid crystal lens array. It can display 2D images without resolution loss and 3D images together. The multi-functional LC lens array has advantages of low driving voltage and easy-fabricated to be compatible with LCD technology. The 3D crosstalk for dual-orientation is 10.8%(Vertical) and 29%(Horizontal). For the 3D Air-touch system, we proposed a simple depth sensing structure which consists of coded optical barrier above embedded photo sensors. By controlling the gap and displacement between barrier aperture and photo sensors, the depth(z) position of fingertip can be captured easily. Besides, along with touch algorithm, the system was able to separate multiple touch points and render 2D coordinate (x,y) we built a prototype on a 4-inch panel to test the feasibility. The system was composed of 1 xy-sensor and 4 z-sensors where the working range in depth was 0 to 35mm with maximum error less than 5 mm. In addition, the system supported upmost 3 inputs simultaneously.

ACKNOWLEDGMENT

This work was financially supported by National Science Council, Taiwan, under contrasts NSC101-2221-E-009-120-MY3, and the polyimide was kindly supported by Chisso Corporation.

REFERENCES

[1] Takagi, S. Uehara, M. Kashiwagi and M. baba, "Function Integrated LC GRIN Lens for Partially Switchable 2D/3D Display", SID Symp. Dig., Vol. 44, pp. 162-165, 2013.

[2] M. Kashiwagi, M. Uehara, S. Takagi and M. baba, “LC GRIN Lens Mode with Wide Viewing Angle for Rotatable 2D/3D Tablet”, SID Symp. Dig., Vol. 41, pp. 154–157, 2013.
[3] Y.P. Huang and C.W. Chen, “Superzone Fresnel Liquid Crystal Lens for Temporal Scanning Auto-stereoscopic Display”, IEEE/OSA Jol. of Display Tech., Vol. 8, No. 11, pp.650 – 655, 2012.
[4] Y.P. Huang, L.Y. Liao, and C.W. Chen, “2D/3D Switchable Autostereoscopic Display with Multi-electrically Driven Liquid Crystal (MeD-LC) Lenses”, J. Soc. Inf. Display , Vol. 18, No9, pp.642-646, 2010.
[5] P. Kauff, N. Atzpadin, C. Fehn, M. Müller, O. Schreer, A. Smolic, et al., "Depth map creation and image-based rendering for advanced 3DTV services providing interoperability and scalability," Signal Processing: Image Communication, vol. 22, pp. 217-234, 2007.
[6] R. Schulein, M. DaneshPanah, and B. Javidi, "3D imaging with axially distributed sensing," Optics letters, vol. 34, pp. 2012-2014, 2009.
[7] R. Ng, M. Levoy, M. Brédif, G. Duval, M. Horowitz, and P. Hanrahan, "Light field photography with a hand-held plenoptic camera," Computer Science Technical Report CSTR, vol. 2, 2005.
[8] C.W. Chen, M. Cho, Y.P. Huang, and B. Javidi, "Three-dimensional imaging with axially distributed sensing using electronically controlled liquid crystal lens," Optics Letters, vol. 37, pp. 4125-4127, 2012.
[9] J. Kuang, H. Yamaguchi, C. Liu, G. M. Johnson, and M. D. Fairchild, "Evaluating HDR rendering algorithms," ACM Transactions on Applied Perception (TAP), vol. 4, p. 9, 2007.
[10] K. Bredies, N. A. Mann, J. Ahrens, M. Geier, S. Spors, and M. Nischt, “The multi-touch soundscape renderer,” AVI '08: Proceedings of the working conference on Advanced visual interfaces 466-469, 2008.
[11] M. Tsuboi, S. Kimura, Y. Takaki, and T. Horikoshi, “Design conditions for attractive reality in mobile-type 3-D display,” J. Soc. Inf. Disp. vol. 18, 698-703, 2010.
[12] S. Jumisko-Pyykk, M. Weitzel, and D. Strohmeier, “Designing for user experience: what to expect from mobile 3d tv and video?” Proceedings of the 1st international conference on Designing interactive user experiences for TV and video, 183-192, 2008.
[13] W. Maphepo, Y. P. Huang, and H. P. D. Shieh, “Enhancing the Brightness of Parallax Barrier Based 3D Flat Panel Mobile Displays without Compromising Power Consumption,” IEEE/OSA J. Display Technol. vol. 6, 60-62, 2010.
[14] J. Konrad and M. Halle, “3-D displays and signal processing,” Signal Processing Magazine, vol. 24, 97-111, 2007.
[15] T. Schou and H. J. Gardner, “A Wii remote, a game engine, five sensor bars and a virtual reality theatre,” In Proceedings of the 19th Australasian conference on Computer-Human Interaction: Entertaining User Interfaces, 231-234, 2007.
[16] C. Hand, “A Survey of 3D Interaction Techniques,” Computer Graphics Forum, vol. 16, 269-281, 1997.
[17] A. Olwal, S. DiVerdi, N. Candussi, I. Rakkolainen, and T. Hollerer, “An immaterial, dual-sided display system with 3D interaction,” Virtual Reality Conference 279- 280, 2006.
[18] M. Hirsch, D. Lanman, H. Holtzman, and R. Raskar, “BiDi Screen: A Thin, Depth-Sensing LCD for 3D Interaction using Light Fields,” ACM SIGGRAPH Asia 62-65, 2009.
[19] G. D. Morrison, “A camera-based input device for large interactive displays,” IEEE Computer Graphics and Applications, vol. 25, 52-57, 2005.
[20] A. D. Wilson, “TouchLight: an imaging touch screen and display for gesture-based interaction,” ICMI '04 Proceedings of the 6th international conference on Multimodal interfaces, 69-76, 2004.
[21] D. Wilson, “Playanywhere: A Compact interactive Tabletop Projection-Vision System,” UIST '05 Proceedings of the 18th annual ACM symposium on User interface software and technology, 83-92, 2005.
[22] Abileah, W. Boer, T. Larsson, T. Baker, S. Robinson, R. Siegel, N. Fickenscher, B. Leback, T. Griffin, and P. Green, “Integrated Optical Touch Panel in a 14.1″ AMLCD,” SID Symposium Digest 35, 1544- 1547, 2004.
[23] K. Yi, C. Choi, S. Suh, B. Yoo, J. J. Han, D. Park, and C. Kim, “45.2: Distinguished paper: Novel LCD display with a sensible backlight,” SID Symposium Digest of Technical Papers vol. 41, 673-676, 2010.
[24] Brown, D. Montgomery, J.-L. Castagner, H. Kato, and Y. Kanbayashi, “31.3: A system LCD with integrated 3-dimensional input device,” SID Symposium Digest of Technical Papers vol. 41, 453-456, 2010.
[25] W. d. Boer, A. Abileah, P. Green, T. Larsson, S. Robinson, and T. Nguyen, “56.3: Active matrix LCD with integrated optical touch screen,” SID Symposium Digest of Technical Papers vol. 34, 1494- 1497, 2003.
[26] G.Z. Wang, M.C. Ma, S.Y. Tung, Y.P. Huang, H.W. Tseng, J.C. Lo, and C.H. Kuo, “A Virtual Touched 3D Interactive Display with Embedded Optical Sensor Array for 5-axis (x, y, z, θ, φ) Detection,” SID Symposium Digest 42, 737-740, 2011.