Autostereoscopic three-dimensional display with high dense views and the narrow structure pitch

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An auto-stereoscopic three-dimensional (3D) display method with the narrow structure pitch and high dense viewpoints is presented. Normally, the number of views is proportional to the structure pitch of the lenticular lens array. Increasing the density of views will decrease the spatial display resolution. Here a lenticular lens array with one pitch covering 5.333 subpiexels and a novel subpixel arrangement method are designed, and a 32 view 3D display is demonstrated. Compared with the traditional 6-view 3D display, the angular resolution and the displayed depth of field are significantly improved.

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Recently, the development of three-dimensional (3D) display techniques has increasingly drawn interests. Holographic can be used to display a description of 3D object[1−3]. However, it is difficult to realize high quality real-time 3D video in the near future. Auto-stereoscopic 3D displays with the liquid crystal display device and the lenticular sheet provide an easy method to realize the glass-free 3D display, which normally distributes the pixels of the LCD device to 5-11 view-points[4−8]. However, the crosstalk and aliasing occur in boundary influence the image quality, and double image effect will disturb the visual feeling for the moving observer. Increasing the view density was proposed to resolve the visual fatigue caused by the accommodation-vergence conflict and provides smooth motion parallax[9−12]. In addition, it is well known that the perceived depth of a scene on an autostereoscopic 3D display is highly correlated to the amount of views or perspectives. Recently, we demonstrated a natural 3D display with smooth motion parallax[12]. With active partially pixelated masks, 500 views from captured serial pictures and 1200 views from a computer numerical mode could be observed in the 56° viewing angel.

Without active tracing devices, the amount of viewpoints is equal to the number of sub-pixels covered by one pitch of the lenticular lens array for the traditional autostereoscopic 3D display. To increase the density of viewpoints, wider pitch should be used. However, the spatial resolution is inversely proportional to the width of pitch, and the wide structure pitch decrease the perceived 3D experience. Here, a new arrangement method of sub-pixels is demonstrated to provide 32-visual views based on the designed lenticular lens array with the narrow structure pitch.

Figure 1 shows the arrangement of subpixels in LCD and the lenticular lens array, which can provide high dense viewpoints with narrow pitch. One structure pitch of the lens array covers five and one third sub-pixels' width. To take advantage of the sub-pixels in the vertical direction, the angle of slanted lenticular lens array is arctan(1/6). This structure decreases the vertical resolution twice and provides more visual views in the horizontal direction. In the range of dashed line, there are thirty-two sub-pixels and three pitches, which constitute display unit realizing 3D display with 32 visual viewpoints.

For the traditional autostereoscopic 3D display, the different pitches of lenticular lens array distribute the covered sub-pixels into the same viewing zone. The viewing points formed by different lenses are overlapped accurately. Here, the pitch is not integral multiple of subpixels' width, and the covered sub-pixels are arranged from different relative positions of corresponding lenses in a display unit. It is assumed that the width of the sub-pixel is the unit length. As shown in Fig. 1(a), two rows of subpixels covered by three pitches are marked with different numbers. The sub-pixels start from zero unit length for area (1), one second unit length for area (2), two third unit length for area (3), one sixth unit length for area (4), one third unit length for area (5), negative one sixth unit for area (6), and every area is covered by one pitch. The different reference position between the sub-pixels and the areas in a display unit will distribute the 32 sub-pixels into 32 different viewpoints.

To further observe the relative position of the 32 subpixels and six areas, the arrangement of six areas in one display unity and their corresponding sub-pixels separately is given in Fig. 1(b). We can see that these subpixels locate at different relative positions for the lenticular lens array which is in front of them. Since the subpixels and the corresponding lens arrays in a display unit have the relative position deviation, the directed viewpoints are formed at different locations in the horizontal direction. The distance between the viewpoints which are formed by the adjacent sub-pixels covered by one lens pitch is set to be w.

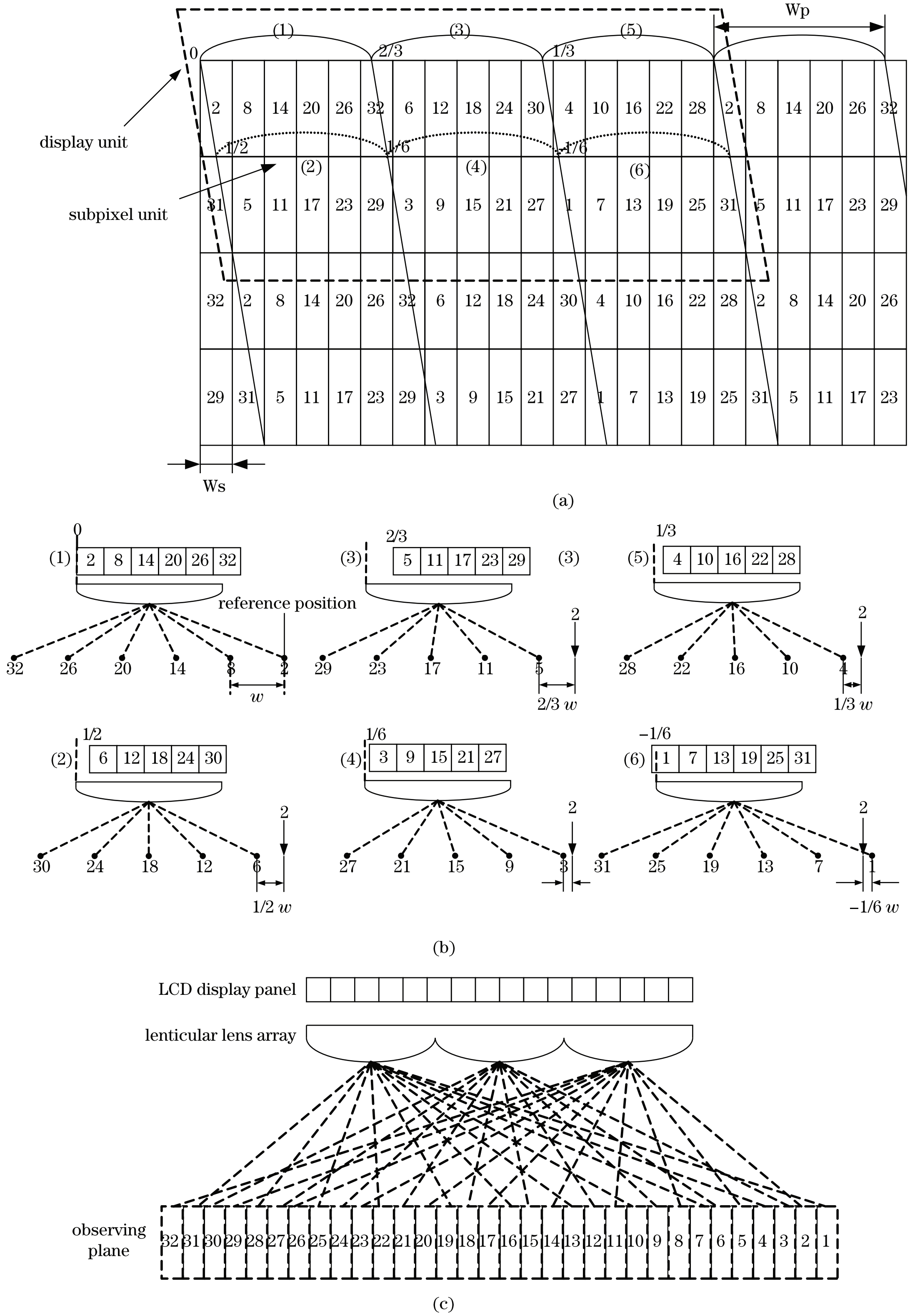

Fig. 1. The 32-view auto-stereoscopic 3D display, (a) Arrangement of sub-pixels. (b) The equivalent arrangement of sub-pixels for a display unit. (c) The viewpoints at the observing plane.

The position the first viewpoint at the observing plane for the area (1) is assumed as the reference position. The first viewpoint of area (1), area (2), area (3), area (4), area (5), and area (6) are formed at the position of 0, $1/2w$, $2/3w$, $1/6w$, $1/3w$ and $-1/6w$, respectively. According to the space position, they are second, fifth, sixth, third, fourth and first viewpoints of the display system. The second viewpoints of 6 areas are the eighth, twelfth, eleventh, ninth, tenth and seventh viewpoints. The 32 sub-pixels in one display unit are distributed to form different points at the observing plane, as shown in Fig. 1(c). For the LCD device with 1920×1080, 360×540 display units are used to display the 32 parallax image sequences or 32 channel parallax videos.

To compare the presented display method with the traditional autostereocopic 3D display method, the 32 view and 6 view display configurations are designed and fabricated, and their corresponding parameters are listed in Table 1.

Table 1. The Main Parameters of Two 3D Display Configurations

Parameter	32-view Display	6-view Display
Screen Size (in.)	27	27
Screen Resolution	1920×1080	1920×1080
Sub-pixel Width W_s (mm)	0.1038	0.1038
The Number of Subpixels Covered by One Structure Pitch N_p	5.333	6
Structure Pitch W_p (mm)	0.552	0.621
Focus Length of Lens (mm)	5.52	6.21
Number of Viewpoits N_s	32	6
Viewing Zone W_b (cm)	25	25
Viewing Distance z_s (m)	2.5	2.5

To realize high performance 3D display, the sufficient display angular frequency bandwidth can avoid aliasing phenomenon[13]. As shown in Fig. 2, the value of the view dependent sub-pixels is defined as the angular resolution. The angular resolution for the 32-view 3D display is improved 5.33 times than that for the 6-view 3D display. Here, the angular frequency bandwidth analyses method of literature[13] is applied. The high resolution screen is defined as the v coordinate. The interval of view dependent sub-pixels is expressed as Δv, and it is determined by $\Delta_v = \frac{N_p * W_s}{N_s}$. The angular frequency bandwidth ϕ is expressed as

$$|\phi| \leqslant \frac{\pi}{\Delta v}. \quad (1)$$

According to the Eq. (1), the smaller value of Δv can provide larger display angular frequency bandwidth. The angular frequencies bandwidth of the proposed display system is significantly improved. It means more parallax images' information can be provided. Large number of views can offer smooth visual effect without burly.

For a real scene in the space, the viewer expects to observe continuous images. If the perspectives are sufficiently close and the viewpoints are sufficiently dense together, the perceived 3D effect is experienced with the smooth motion parallax, just like to see a real scene. To avoid the inter-perspective aliasing, the depth range of the auto-stereoscopic display is limited. According to the geometrical relationship and visual principle, the maximum displayed clear depth z_0 is given as[14]:

$$z_0 = \frac{z_s}{\frac{W_s}{W_s} + 1}, \quad (2)$$

where the minimum spot size of W_i is equal to the pitch of lens W_p, the viewpoint width W_s is determined by the ration between the width of viewing zone W_b and the number of viewpoints N_s. The maximum displayed clear depth of 32-view display and 6-view display without inter-perspective aliasing are 16.5 and 3.67 cm, respectively. It is obviously that the proposed 3D display method significantly improves 3D experiences

The light intensity distribution of each view can be used to evaluate the uniformity of 3D display. The measured normalized luminance of all the views is given in Fig. 3. The fluctuation of the curve in Fig. 3(b) is observably decreased, compared with that in the Fig. 3(a). The small light intensity fluctuation means that the proposed method can provide smooth motion parallax at the observing plane.

Figure 4 illustrates the displayed results of the two display methods with the same scene. Both of them have

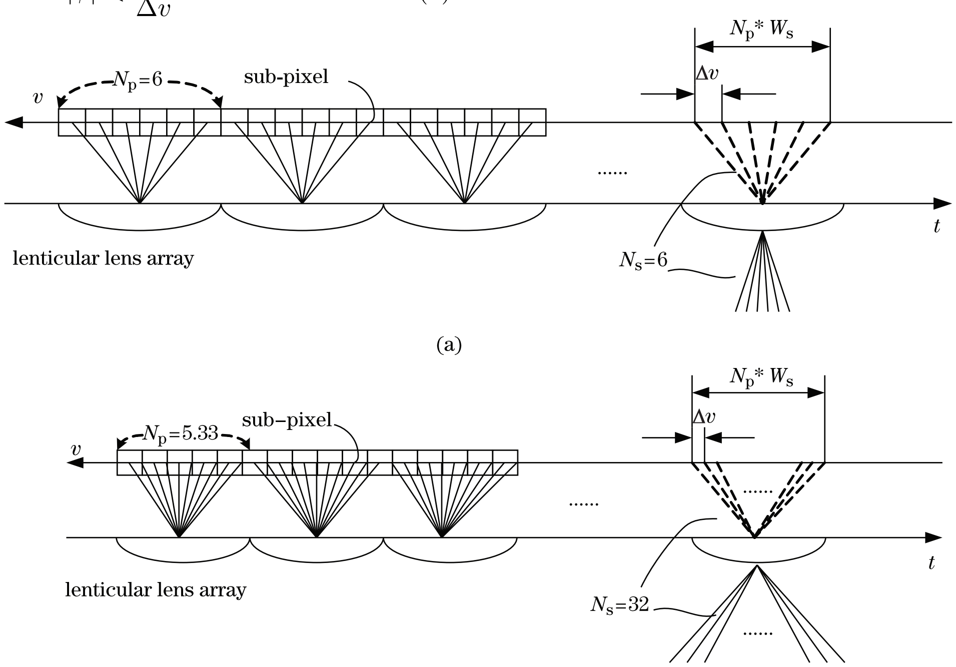

Fig. 2. Parameters which are used to calculate the display angular resolution (a) traditional 6-view three-dimensional display (b) the proposed 32-view three-dimensional display.

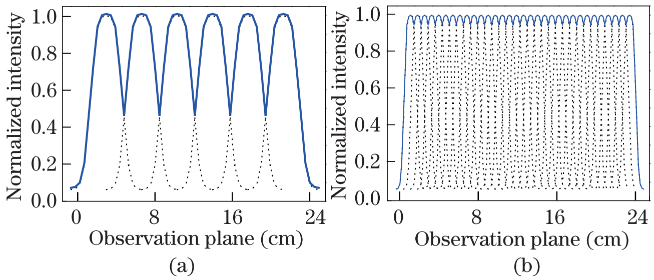

Fig. 3. Light intensity distribution of different views along the horizontal direction at the observation plane: (a) the normalized luminance of 6-view display, (b) the normalized luminance of 32-view display.

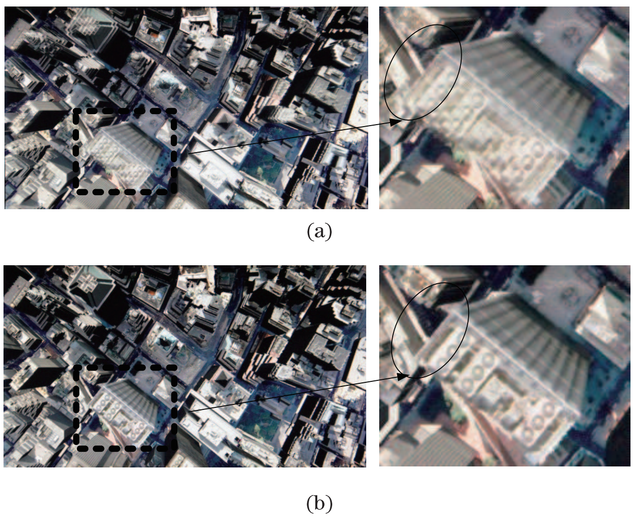

Fig. 4. Images of a scene "Manhattan" captured at its observing plane: (a)result of 6-view display. (b) result of 32-view display.

the maximum displayed depth of 15 cm. In Fig. 4(a), the edge of the buildings marked with circles is much blurry. In Fig. 4(b), the 32-view display can effectively eliminate the aliasing and the displayed 3D image is clearer than that in Fig. 4(a).

In conclusion, a 32 view 3D display is demonstrated to provide high dense viewpoints with the narrow structure pitch in the lenticular lens array. A lenticular lens array with one pitch covering 5.333 subpiexels and a novel subpixel arrangement method are designed. The angular resolution and the displayed angular frequency bandwidth are significantly improved. The experimental result shows that the demonstrated 32 view 3D display can effectively eliminate the aliasing and provide clearer 3D image.

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