

High dense views auto-stereoscopic three-dimensional display based on frontal projection with LLA and diffused screen

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Received July 25, 2014; accepted October 24, 2014; posted online December 12, 2014

We present a high dense views auto-stereoscopic three-dimensional display method with the projectors array and lenticular lens array (LLA) screen. The principle and configuration are demonstrated. This display method utilizes lenticular screen to modulate the information of projectors. To increase the dense of views, we propose a novel arrangement way of projectors array. In the experiment, the viewer can obtain smooth motion parallax and evident stereo feeling at optimal distance. Through analyzing and observation, the maximum display depth is found to be more than 50 cm.

OCIS codes: 100.0100, 100.6890, 330.1400.

doi: 10.3788/COL201513.011001.

Presenting a real three-dimensional (3D) scene in the space has always been the dream of human beings. Various studies are currently under way to realize the natural 3D display^[1-10]. Holographic can be used to display a description of 3D object^[3,4]. 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 (LCD) device and the lenticular sheet provides an easy method to realize the glass-free 3D display, which normally distributes the pixels of the LCD device to 5-11 viewpoints^[5-7]. However, the resolution of each single view is inversely proportional to number of views. For example, when the flat panel display with the resolution 1920×1080 is used to achieve the auto-stereoscopic display with nine views, the parallax images' resolution is 640×360. In Refs. [8,9], the 3D projection display can present four full-resolution 3D images. To simulate the natural 3D vision, high dense of views is necessary. High dense views not only provide smooth motion parallax but can also present large display depth^[10,11]. Here, we demonstrate an auto-stereoscopic 3D display with high dense views based on frontal projection. We use 24 projectors to display the full-color 3D space information of the object through the lenticular lens array (LLA) screen with the size of 2×1.125 (m). Observer can obtain 24 views in 300 mm range in the horizontal direction.

The auto-stereoscopic 3D frontal projection display system consists of a group of projectors and a lenticular sheet. Figure 1 illustrates the view's formation principle of one projector. The projector is set at the front of the projection screen. A diffuse reflection screen is behind the lenticular sheet. The distance between the diffuse reflection screen and lenticular sheet is f , which is the focal length of the lenticular sheet. It assumes that the

light projected from the projector can pass through the lenticular sheet completely and form stripes on the diffuse reflection plane. The stripe diffuses through different lenses and forms different views on the same horizontal line with the projector. As shown in Fig. 1, observer obtains the parallax image of the projector at the viewing positions O_1 , O , and O_2 . The distance between the adjacent viewing points formed by a projector is T . T is the width of a viewing zone of the 3D display system, L is the projection and observation distance, and the pitch of the LLA is P . According to the geometric analysis, we can obtain

$$T = P \times \frac{L+f}{f}. \quad (1)$$

The display depth is determined by the dense of views, the relation between them can be expressed as in Fig. 2. W_1 is the minimum spot size and W_s is the width of one view. To avoid the inter-perspective aliasing, the depth range of the auto-stereoscopic display is limited^[10].

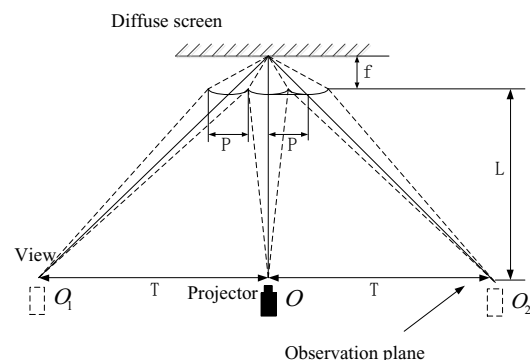


Fig. 1. Formation principle of one view.

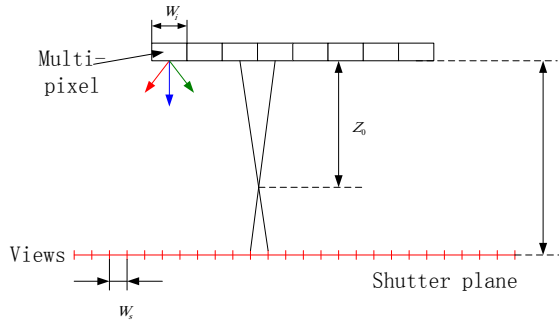


Fig. 2. Diagram of the maximum display depth without inter-perspective aliasing.

The maximum displayed clear depth z_0 is given as

$$z_0 = \frac{L}{\frac{W_s}{W_i} + 1}. \quad (2)$$

As the size of projectors is larger than the wanted interval, many 3D projection displays^[8,9] arrange the projectors several rows to improve the employment efficiency of projectors. However, as the top and bottom projectors are put far away from the screen, the distortion and phase difference are serious, more number of rows mean worse visual effect. We assume the maximum rows are R under ideal visual feeling. The size of projectors is w . The dense of the projectors can be expressed as R/w which is also the views dense.

To further enhance the dense of views, the proposed system utilizes the periodic characteristics of LLA. A multi-zone input of projectors method is used. As shown in Fig. 3, the 3D frontal projection display system consists of a group of projectors and a lenticular screen. The lenticular screen consists of a LLA and a diffuse screen. In theory, the higher the diffuse efficiency, the better the views are formed. To obtain the ideal visual effect, we use high-efficiency diffuse material on the diffuse screen.

Here, the projectors are put in twice the width of a viewing zone ($2T$). The arrangement of projectors and the formation views are shown in Fig. 3. Twenty-four parallax images come from different projectors which are located at 24 different positions. The figures signed on the projectors represent the parallax images' serial numbers.

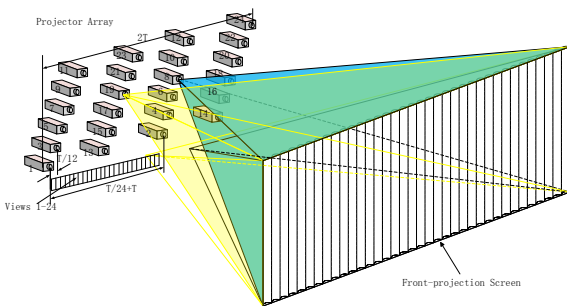


Fig. 3. Configuration of the proposed auto-stereoscopic 3D projection system.

The projectors signed with even and odd numbers are arranged in the first T width and the second one, respectively. The horizontal distance between the first and the third projectors is $T/12$, the interval between the projectors marked 1 and 2 is $T/24$. Twenty-four parallax images are put in a viewing zone in the horizontal direction at the viewing plane. Under this kind of arrangement, the dense of views is increased twice.

The frontal projection high dense views auto-stereoscopic 3D display system employs 24 projectors and a LLA screen size of 2×1.125 (m). The width of the projector's lens is 12.5 mm, and the width of one view zone is 12.5 mm. The proposed display system distributes the viewing zones in 300 mm range. The number of projectors is calculated by dividing 300 by 12.5. Larger number of projectors will bring crosstalk into the system. Smaller number of projectors will cause non-uniform light distribution.

In the prototype system, the pitch of the lenticular sheet is 1.5 mm, the focal length of the lenticular sheet is 20 mm. The viewing plane is set at 4 m away from the screen. According to Eq. (1), the value of T can be calculated. The display parameters are listed in Table 1.

The resolution of one view and views' dense are the evaluation of the 3D display system. The display bandwidth is decided by the two parameters^[12]. Each view's resolution is 1280×800 , which is higher than the traditional LCD LLA 3D display. Twenty-four views are formed in 30 cm width's viewing range, which provides high views' dense.

In the system, four computers are used to control 24 projectors and one computer is used to synchronize the four computers. The type of the graphic card is "ATI FirePro V7700" which can provide images to six projectors, simultaneously. The power consumption of one projector is 44 W. There are 24 projectors in the whole system. The power consumption of one computer is 200bW. So the total consumption of the whole display system is 2056 W.

Table 1. Main Parameters of the 3D Display Configuration

Parameter	24-view Display
Screen Size	2×1.125 (m)
Projector's Resolution	1280×800
Structure Pitch W_p (mm)	1.5
Focus Length of Lens (mm)	20
Number of Views N_s	24
Number of Projectors	24
Viewing Zone T (mm)	300
Viewing Distance L (m)	4
Tolerance of LLA's Pitches (μm)	± 1
Angle (deg.)	33.4



Fig. 4. Configuration of the 24 views auto-stereoscopic 3D display system.

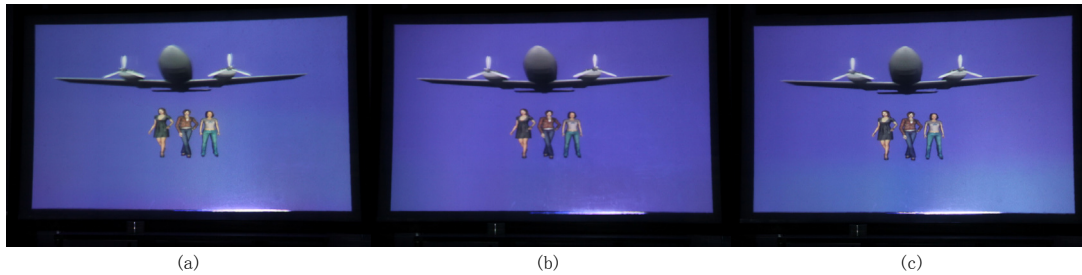


Fig. 5. Pictures captured from different directions: (a) angle: 6.6° , distance: 4 m; (b) angle: 7.8° , distance: 4 m; (c) angle: 8.3° , distance: 4 m.

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 ratio between the width of viewing zone W_b and the number of viewpoints N_s . The maximum displayed clear depth is more than 50 cm.

Figure 4 shows the structure of the proposed system. In Fig. 5, the views from different directions are captured. In the experiment, the observer can obtain smooth motion parallax and outstanding visual effect in a viewing zone.

In conclusion, we present a novel 3D display system with 90 inches screen and 24 views. The principle and structure of the prototype system are demonstrated. To increase the number of views in a viewing zone, the arrangement of projectors are set in several rows and they are set in twice the width of viewing zone. Through this method, more projectors can be arranged in several viewing zones to further increase the dense of views. By calculation and experiment, it is found that this kind of display provides smooth motion parallax and evident stereo effect with large screen.

The 3D display which can provide natural scenes and natural-like 3D simulation environments is increasingly drawing interest. There are many potential applications, such as scientific research, industry, medical operation, military affairs, architecture design, mapping, and entertainment. The proposed display system can not only be used in the above domains but also has special advantages in advertisement and exhibition display. The advantages include large display size, huge amount of views, and obvious display depth, which can meet many observers' request, simultaneously.

This work was partly supported by the National Natural Science Foundation of China (No. 61177018), the National "863" Program of China (No. 2012AA011902), the Program for New Century Excellent Talents in University (No. NECT-11-0596), the Program of Beijing Science and Technology Plan (Nos. D121100004812001 and Z131100000113009), and the Beijing Nova Program (No. 2011066).

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