A Liver Surgery Simulator Using Full HD Autostereoscopic Displays

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Abstract  We present a liver surgery simulator using full-HD autostereoscopic displays. We have developed two kinds of autostereoscopic displays to keep on showing a full-HD 3D image to a viewer who moves freely in front of the display. One is a 3D display based on time-division multiplexing directional backlight and the other is a 3D display based on time-division multiplexing parallax barrier. We have applied the developed simulator using the 3D displays with different specifications to the education of medical students. The result of the questionnaires suggests that 3D visualization is effective and that reduction of crosstalk plays an important role to promote medical use of 3D displays.

Keywords: high resolution, medicine, crosstalk, directional backlight, parallax barrier, time-division multiplexing.

1. Introduction

We have been engaged in developing high definition autostereoscopic display systems for medical use. For the purpose of medicine, the resolution matters most. Autostereoscopy, which allows the viewers to see 3D images without wearing glasses, is also preferable because it allows eye-contact among the medical staff.

Recently, several autostereoscopic displays that attain full resolution of the display panel have been proposed. One way is to use a directional backlight composed of a light guide film and two light sources\(^1\)-\(^3\). The drawback of this method is the fixed viewing zone. To enlarge the viewing zone, directionality of backlight has to be controlled to follow the motion of the viewer, which often requires thick optical systems\(^4\)-\(^5\).

To present a full-HD 3D image to a viewer who moves freely, we have developed two kinds of autostereoscopic displays. One is a 3D display based on time-division multiplexing directional backlight composed of a convex lens array\(^6\)-\(^8\) and the other is a 3D display based on time-division multiplexing parallax barrier\(^10\)-\(^13\). So far we have made several prototype systems based on these two methods. The early models had drawbacks such as low intensity and strong crosstalk. In 2015 we started using the prototype 3D display based on time-division multiplexing directional backlight for the education of medical students. Liversim, which is a software to simulate liver surgeries\(^14\), is implemented on a 2D display and the 3D display so that they can be compared with each other.

In this paper we introduce the 3D liver surgery simulators we have developed and report the results of the evaluation by the medical students. This paper is organized as follows. In Section 2 the autostereoscopic display based on time-division multiplexing directional backlight is explained. In Section 3 the autostereoscopic display based on time-division multiplexing parallax barrier is explained. In Section 4 the results of the evaluation on the 3D liver surgery simulators based on time-division multiplexing directional backlight are reported. In Section 5 the results of the evaluation comparing two kinds of autostereoscopic displays are reported and the paper is concluded in Section 6.

2. 3D display with directional backlight

The principle of the conventional directional backlight using a convex lens array is shown in Fig. 1. When dot matrix light sources are placed behind the convex lens array so that the distance between them may be equal to
the focal distance of the elemental lens of lens array, collimated directional light is realized. By changing the position of the luminous light sources, the directionality of light is controlled. When the directional backlight to each eye alternates synchronously with the alternation of left-eye and right-eye images on the LCD panel, the viewer can see a stereoscopic image without wearing special glasses. By increasing the number of light sources, multiple viewers can observe the stereoscopic image simultaneously\cite{15-18}.

The conventional system shown in Fig. 1 has two major problems. One is the aberration of the lenses, which causes crosstalk due to the overlap of the light sources for the left eye and the right eye. The other is poor image quality due to the non-uniform luminance and the distinct seam of the coarse lens array. Light rays going through a lens generally weakens as the angles become wider, which causes emergence of bright area and dark area in each elemental lens.

The aberration can be reduced by inserting a large convex lens behind the LCD panel\cite{7}. To remove the seam of lens and the non-uniformity of intensity from the image, we combine a lens array with various phase shift and a vertical diffuser\cite{8}. The elemental lenses are aligned so that the phase of lens placement in each row may differ from one another as shown in Fig. 2. Since the seam of the lenses appear only once in the vertical direction, the vertical diffuser can smooth the seam enough and the image with homogeneous intensity is attained.

The first prototype based on this idea was made by using two LCD panels that run in the frame rate of 120 Hz, one for the imaging and the other for the dot matrix light source for simplicity. Ideally the dot matrix light source should be LED arrays for the reason of energy efficiency. Indeed the first prototype had the problem of low intensity and strong crosstalk, which amounts to 45 %. To overcome the problem of luminance we made a revised system where the backlight is replaced from 63 W LED arrays to 526 W LED arrays.

To solve the problems of crosstalk, we investigated the cause of crosstalk to find out the incomplete time-division multiplexing and the stray light caused by the lens array composed of Fresnel lenses are the main causes.

As shown in Fig 3, the LCD panels we used in the first prototype scan the image serially, which causes severe crosstalk, for the vertical diffuser mixes the backlight of the odd frame and the even frame. (Here a red image and a green image are shown alternately on the screen.) When the LCD panels switch the image in a parallel manner by dividing the panel areas, the image of the odd frame and the even frame do not appear at the same time as shown in Fig. 4. In the second prototype, we used these LCD panels and measured the crosstalk with a luminance meter to find out the crosstalk level dropped from 45 % to 18 %.

The mechanism of stray light caused by the grooves of
Fresnel lenses is explained in Fig. 5. One way to remove the stray light is to narrow the viewing angle of the backlight panel so that the light from a steep angle may be cut. To achieve this we placed a privacy filter on the surface of the LCD panel that works as the dot matrix light source and measured the crosstalk to find out that the crosstalk level dropped from 18% to 13%, while the luminance is also reduced due to the addition of the filter.

3. Time-division multiplexing parallax barrier

In the conventional parallax barrier system, the viewing position is fixed and the resolution is half that of the original display panel. Time-division duplexing parallax barrier solves the problem of resolution loss caused by the conventional parallax barrier. The time-division duplexing parallax barrier systems show two kinds of images and parallax barrier patterns alternately at a refresh rate of 120 Hz\(^{19,20}\). These systems, however, cause crosstalk when the viewer is not located at the proper viewing point.

To achieve high resolution and expansion of the viewing areas free from crosstalk, time-division quadruplexing parallax barrier has been proposed (Fig. 6\(^{10}\). Here 4 viewpoints and the corresponding images are denoted as A, B, C and D. The slit is shifted by one
pixel at each frame and drawing of a full resolution image is completed after 4 frames. Though flicker emerges because of the quadruple time-division, it does not stand out when the slits of the parallax barrier are as fine as 1 pixel wide. The flicker can be further suppressed by applying anaglyph parallax barrier to this system.

The viewing zone without crosstalk can be extended with "L-L-R-R" alignment in the 4 view system, where the left-eye image is delivered to 2 viewpoints and the right-eye image is delivered to the other 2 viewpoints. The left-eye image is shown at points A and B, and the right-eye image is shown at points C and D. If the left eye is between points A and B and the right eye is between points C and D, 3D images without crosstalk can be observed. By changing the slit position in accordance with the viewer's position by subpixel unit, continuous stereoscopy is maintained. The prototype based on this method reduce the crosstalk level to 6%.

4. Evaluation of 3D surgery simulator based on time-multiplexing directional backlight

Liversim is a real-time virtual hepatectomy simulation software that provides 4 basic functions: viewing 3D models from arbitrary directions, changing the colors and opacities of the models, deforming the models based on user interaction, and incising the liver parenchyma and intrahepatic vessels based on user operations (Fig. 7).

We implemented Liversim on the 3D displays based on time-division multiplexing directional backlight we introduced in the previous section as shown in Fig. 8. To evaluate the effectiveness of the 3D displays, we asked medical school students to answer the following questions after trying both 2D version and 3D version of Liversim: (Q1) Do you feel depth in the 3D version? (Q2) Which gives better understanding of liver deformation? (Q3) Which gives better understanding of blood vessel stream? (Q4) Do you think autostereoscopy is helpful?

First we asked these questions to 24 medical students from age 21 to 30 (13 male, 11 female) who tried 2D Liversim and 3D Liversim based on the first prototype (45 % crosstalk, 63 W backlight) during the educational program from August 17 to October 13, 2015. In the first prototype, a pair of 24 inch TFT panels from BenQ XL2420 were used for imaging and the dot matrix light control. The lens array was composed of 650 elemental lenses (20 mm wide and 12 mm high) whose focal distance was 30 mm. A large convex Fresnel lens whose focal distance was 800 mm was placed behind the imaging panel. Kinect v2 was used for head tracking.

Next we asked the same questions to 28 medical students from age 21 to 30 (18 male, 10 female) who tried 2D Liversim and 3D Liversim based on the second prototype (18 % crosstalk, 526 W backlight) during the educational program from February 23 to May 9, 2016. In the second prototype, a pair of 24 inch TFT panels from Asus VG248 were used for imaging and the dot matrix light control. The same lenses and the head-tracking device were used in the second experiment also.

Figs. 9 through 12 show the results of the evaluation by the medical students. As these figures show, the second prototype attains better scores in every question. Chi-square tests show that improvement is statistically significant where p values are all far below 0.01 in every question.

Also almost all the students answer that 3D is better than 2D and no students answer that 2D is better than 3D in questions 2 and 3 after the intensity of backlight is increased and the crosstalk is decreased as shown in...
Thus the effectiveness of 3D displays for the surgery simulator is confirmed.

5. Evaluation of 3D surgery simulator based on time-multiplexing parallax barrier

As the result in the previous section shows, reduction of crosstalk improves the evaluation by the medical students. Therefore use of time-multiplexing parallax barrier is expected to obtain better response by the students, for the crosstalk is further suppressed.

To evaluate the 3D surgery simulator based on time-multiplexing parallax barrier, we implemented Liversim on the prototype display system as shown in Fig. 13. 3D display based on time-multiplexing parallax barrier is labeled as A, while the 3D display based on time-multiplexing directional backlight is labeled as B, both of which are placed side by side for the use of medical students as shown in Fig. 14. We asked 16 medical students from age 21 to 24 (9 male, 7 female) to compare them on Dec. 6, 2016, Jan. 10, 2017, and May 16, 2017. On the first two days the resolution of the image given by time-multiplexing parallax barrier was half HD for the software reason, while the resolution was full HD on the last day. We asked the following questions: (Q1) Which gives a better image quality? (Q2) Do you perceive double image? (Q3) Which display do you want to use?

Figs. 15 through 17 show the result of the questionnaire. As shown in Figs. 15 and 16, no significant difference between A and B was found in questions 1 and 2. The crosstalk level measured objectively is far lower in system A than in system B. The reason why significant difference was not found in question 2 may come from the head-tracking problem,
for the camera for head-tracking was placed at the bottom of the display for hardware reason, which more often fails to track the face of the viewer. Fig. 17 shows that system A is evaluated higher than system B for practical use, which may reflect the evaluation of lower crosstalk.

Fig. 18 shows the actual educational scene where a professor is explaining how the 8 hepatic segments can be distinguished by the branching of blood vessels. As this figure shows, eye-contact between a professor and a medical student is enabled due to the autostereoscopy, which helps smooth communication between them.

6. Conclusion

In this paper we have presented a liver surgery simulator using full-HD autostereoscopic displays. We have developed and have used two kinds of autostereoscopic displays that keep on showing a full-HD 3D image to a viewer who moves freely in front of the display. We implement Liversim, a liver surgery simulator, on the 3D displays with different specifications for the purpose of medical education. The result of the questionnaires to medical students suggests that 3D visualization is effective and that reduction of crosstalk plays an important role to promote medical use of 3D displays.

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References


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