Color-Changeable and Touchable Volumetric Display by Projection of Aerial Plasma Emission

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ABSTRACT

Projection of volumetric images with aerial plasma voxels formed by femtosecond laser pulses was performed with two parabolic mirrors with a variable color filter. The projection enables us to change the color of voxels and touch the voxels safely.

1 INTRODUCTION

Volumetric displays create three-dimensional (3D) graphics by drawing volumetric pixels generally called voxels that are visualized by light emission and light scattering. Since the voxels are directly generated as the image points of the object in space, the 3D graphics that satisfy the depth perception of the human can be created. Therefore, users can observe the 3D images without a special equipment from all direction with their naked eye.

Depending on the characteristics of the voxels, volumetric displays can be classified into two types: the light-scattering type and the light-emitting type. Scattering-type volumetric displays using rotating projection screens [1,2], water drops [3], and fog [4], and floating small particles [5-7] have been proposed. These displays can easily form voxels that display multiple colors because the colors of the voxels depend on the projected image. Light-emitting-type volumetric displays using optical fibers [8] have been demonstrated. A variety of kinds of volumetric displays based on laser-induced plasmas [9,10], semiconductor quantum dots [11,12], rare earth elements [13-15] have been reported. They form voxels by laser excitation of the screen material.

In realization techniques of volumetric displays, we focused on laser drawing methods that used voxels formed by optical addressing with laser, and volumetric images rendered by 3D scanning of beams. These methods can render volumetric graphics having wide viewing angle because these do not require physical wiring between drawing space and system to generate voxels. On the other hand, in the conventional systems using laser drawing, the number of voxels for displaying a volumetric image was insufficient due to the limitation of the speed of the 3D scanning system and repetition frequency of the laser source.

In order to solve the above challenge, we have presented volumetric display systems with a holographic laser-drawing method using computer-generated holograms (CGHs) displayed on a liquid-crystal spatial light modulator (LCSLM) [16-19]. Since the holographic laser drawing method can arbitrarily design the parallelization number of focal points by the CGH, it improve the number of voxels that display can form per unit time. In our work of 2016, aerial volumetric display which achieved touch interaction between user and images has been proposed [18]. However, this system capable of displaying aerial volumetric graphics with full-color has still challenge.

In this paper, we propose a volumetric display which can render full-color graphics in mid-air with femtosecond laser-induced plasma as voxel. Figure 1 shows a concept of a method we propose. This display project the aerial plasma graphics with two parabolic mirrors. The emission light from the aerial plasma passes through a variable color filter have a liquid crystal (LC) plate and a polarizer in the process of projecting graphics, and the light have arbitrary color. Therefore, it is also expected to develop into an application of interaction between the volumetric graphics and a user because the user can touch the aerial graphics and the graphics can be changed color.

2 EXPERIMENTAL SETUP

Figure 2 shows an experimental setup. The experimental system were mainly composed of a laser light source, a spatial light modulator (SLM), a laser scanning device, and a projection device. The laser light

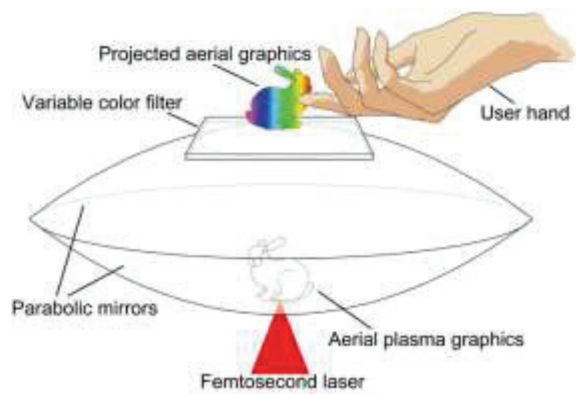

Fig. 1 Display voxels generated by projection of the laser induced plasma emission with two parabolic mirrors

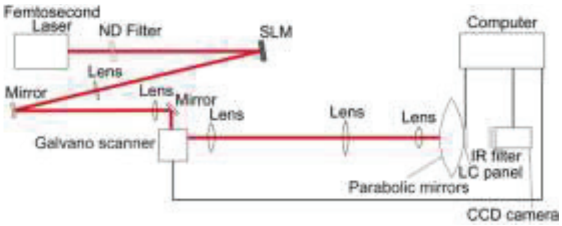

Fig. 2 Experimental setup

source was a femtosecond laser (Micra and Legend Elite Duo, Coherent) with a center wavelength of 800 nm, a repetition frequency of 1 kHz, and a pulse duration of less than 100 fs. The SLM was a liquid crystal on silicon SLM (LCOS-SLM, X10468-02, Hamamatsu). The laser scanner was a galvano motor (GM-1000, Canon) with a driver (GC-201, Canon) and a control board (GB-501, Canon). The projection device for the projection of plasma voxels was composed of a parabolic mirror (MG-20, Shimadzu) and a liquid crystal panel was taken out from the liquid crystal module (SET-6802V2-L043, aitendo).

3 RESULTS

3.1 Angular light-intensity distribution of a voxel

The angular light-intensity distribution of a voxel was measured. This device has a viewing angle that can be observed from all directions in the horizontal direction in Fig. 1, but the viewing angle is limited in the vertical direction. In this experiment, we measured the angle dependence of the light intensity of the voxel image, and obtained the viewing angle.

Measurements were taken by taking voxels at different angles and obtaining the intensity from the pixel values of the image. The plane including the hole on the exit side was set to 0 °, and a semicircular slider was used from there to move the CCD camera to 90 ° in steps of 10 ° around the center of the hole. White, red, green, and blue voxel images were taken at each angle, and the image was taken by moving the plasma generation position from the incident-side hole inward to 12 mm every 2 mm.

Figure 3 shows the graph of the angular characteristics of intensity for each depth of voxel. In this graph, the outermost case (0 mm), the innermost case (12 mm), and the intermediate value (6 mm) are shown. The value is when the color is white. From this graph, it can be seen that as the depth increases, the viewing angle approaches perpendicular to the hole. Therefore, when displaying an image with a height of about 12 mm with this device, it was found that the viewing angle for observing the image at all times was 50 ° to 60 ° with the range overlapping at all depths.

3.2 A two-dimensional drawing

Figure 4(a), (b), (c) shows the experimental results of drawing a two-dimensional image. Drawing was performed by scanning the laser focusing point. The pulse

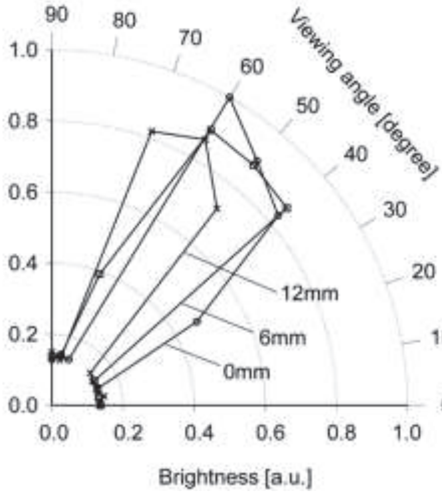

Fig. 3 Angular characteristic of a voxel for the axial position

energy is 0.6 × 10^2 μJ. This is because the plasma generation by scanning requires higher energy than the fixed point. Next, an experiment was conducted to draw a two-dimensional image with multiple colors. There were two methods of giving multiple colors: a method of switching the display color of the liquid crystal on the whole surface during the drawing of a two-dimensional image by scanning, and a method of rotating an image with partially different colors.

Figure 4(d) shows the experimental results for the method of switching the display color of the liquid crystal over the entire surface. The drawing pattern in the method of switching over the entire surface is an image of a snow crystal. The color pattern to be switched was switched in order of red, yellow, green, and blue. From

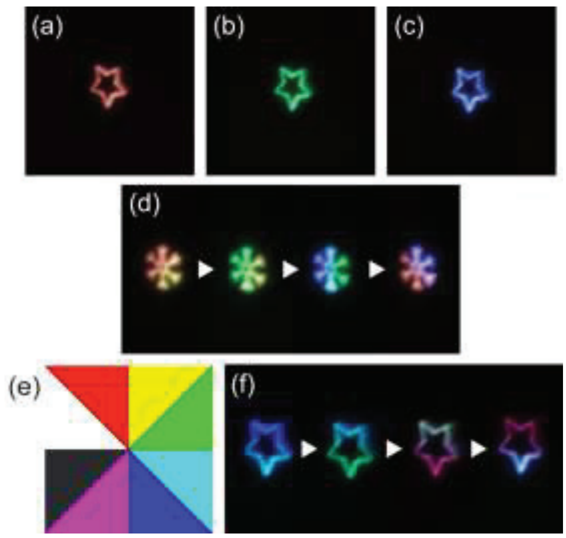

Fig. 4 (a) Red, (b) green, and (c) blue drawn graphics. (d) Switching the color of the entire area of the LC device. (e) An image with rotation displayed on the LC device and (f) its observed images.

these results, it was confirmed that images with multiple colors could be drawn by changing the display color of the liquid crystal during drawing.

Figure 4(f) shows the experimental results of the method of rotating images with partially different colors. Figure 4(e) shows the image to be displayed and rotated. The center of the image was aligned with the center of the hole and rotated around the center of the image. In the experiment, it was observed that the color changed in order as shown in Figure 4(f). This method displays the same results as in Figure 4(e), and the observation results while changing around a circle centered on the device. From this result, this device has the feature that the display color can be changed depending on the viewing angle.

4 CONCLUSIONS

We demonstrated a volumetric display drawing in mid-air. The voxels of this display are created by imaging the laser induced plasma emission with two parabolic mirrors. The color of the voxel can be changed by the liquid crystal panel before imaging. This display had the interactive feature, because the graphics made by this display can be touched without disturbance of the drawing.

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