Development of a time multiplexed HMD type multi-focus 3D display system

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Abstract
The problem of the conflict between eye convergence and accommodation can be induced at Stereoscopic or multi-view 3D display system using binocular disparity. A multi-focus 3D display system was developed, which can solve the problem. LEDs are used instead of galvano scanner and laser to avoid mechanical moving part at the 3D display system.

1. Introduction
3D display is a good candidate of future display. But there are some problems to be solved for popular use of 3D display. One of important problems is the eye fatigue phenomenon when we see 3D image for long time. Due to that, 2D display system could not be replaced by 3D display system yet.

The eye fatigue phenomenon is known as "Mismatch between convergence of both eyes and focus adjustment of each eye" [1, 2]. Therefore, there is a need for a stereoscopic 3D display system which can perfectly satisfy the eye accommodation and convergence. In previous paper, Solutions of this phenomenon were proposed at [3, 4, 5].

In this paper, we developed a HMD type multi-focus system using LEDs as light source in order to reduce system volume and avoid mechanical part. As a result, focus adjustment is possible in this system about one eye.

2. Principle of focus adjustment
Size of pupil of human eye has individual variation and it is within about 2 ~ 8 mm depending on surrounding brightness. The concept about focus adjustment action mechanism of each eye is shown in Figure 1. The condition of the satisfaction of the accommodation is illustrated through three horizontal parallax images within the diameter of the pupil.

When two parallax images, at least, are offered to a condition of minimum diameter of eye pupil, it is possible to focus at a desired depth position. Because focus adjustment is available by controlling thickness of crystalline lens of an eye, depth recognition by only monocular depth cue is possible to different depth positions. There are two different depth virtual point sources in Figure 1. The crystalline lens becomes thicker when an observer wants to focus on point source 1 and becomes thinner when an observer wants to focus on point source 2. The situation about the focus on point source 1 is drawn with solid lines and the situation about the focus on point source 2 is drawn with dashed lines. For example, when observer sees point source 1, blur is occurred in point source 2. Because point source 2 can not be exactly focused on retina.

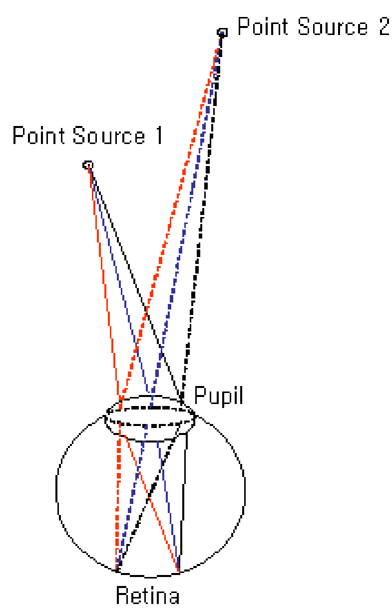

Figure 1. Condition of focus adjustment through three parallax image light rays

3. Experiment

An optical setup for the proposed multi-focus system is at Figure 2. We used LEDs as light sources. To provide 4 parallax images for one eye, we used 4 LEDs. A lens 1(focal length 100mm) is located in front of LEDs. Expanded lights by lens 1 from LEDs are covered the whole surface of the DMD. A DMD (Digital Micro-mirror Device) was used because it has high image resolution and a fast deriving speed. The beam reflected by the DMD includes time multiplexed parallax images. At this time, in order to synchronize between LEDs and parallax images, we used 4 bit ring counter circuit. And reflected beam passes lens 2(focal length 110mm). Also, in order to remove diffracted beams from the DMD except the 0-th order diffraction beam in each LED, we used 4 pinhole at the imaging depth of lens 2. And then the selected 0-th order diffraction beam enters at lens 3 (double lens system). Each entered beam at lens 3 was converged around of eye pupil. The monocular depth cue about displayed 3D object is captured by a video camera.

4. Results

In this experiment, we provided four parallax images by using four LEDs. Objects of parallax images are located at four different positions. Alphabet “K” is located at 250mm, “I” is located at 500mm, “S” is located at 900mm and “T” is located at 2000mm. Sizes of the alphabet are decided to represent depth information.

The results are shown in Figure 3. The photos in Figure 3 are captured by a digital video camera, and the observer can also see the same result by his/her own eye. In Figure 3, when we focus on each alphabet “K” (Figure 3 (a)), “I” (Figure 3 (b)), “S” (Figure 3 (c)), and “T” (Figure 3 (d)), focused alphabets can be clearly seen and other alphabets are defocused (blur effect) by one eye or digital video camera. These results are almost same to the action of accommodation in real world. Also, one blurred circle at each figure is reference real point light source. Therefore we can find the differences about focus depth among four results.

Figure 4 is shown to measured blur effect in one parallax image. Measurement of blur effect at each parallax image is very important in our experimental result because blur effect must be generated by focus adjustment of eye or camera by using two or more parallax images in our experiment. The photos in figure 4 are captured at defined position of our experiment range (0~2000mm). In figure 4, (a) is captured with 0.25m manual focus of video camera. Also, (b) is captured with 0.5m, (c) is captured with 0.9m and (d) is captured with 2m.

We could confirm that each parallax image was not blurred through focus adjustment of camera or eye.

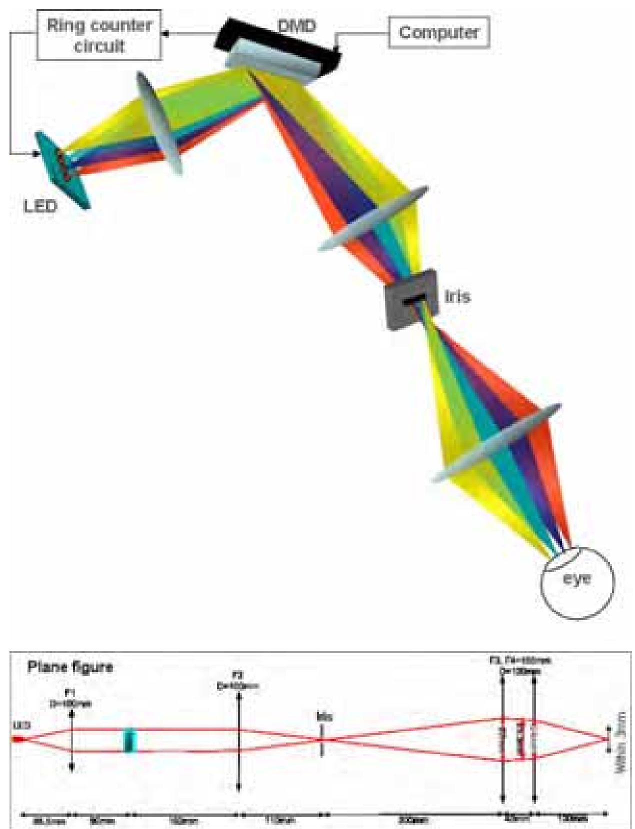

Figure 2. Experimental setup and system profile.

5. Conclusion

In order to remove eye fatigue phenomenon by mismatch between eye accommodation and convergence in stereo or auto-stereoscopic 3D display system, we developed a multi-focus display system using LEDs, which has more advantage than existing system. First advantage, this system can provide horizontal and vertical parallax effects in a case of 2D LED array. Second, the developed SMV systems [3, 4] are based on mechanical part like a polygon mirror or galvano scanner. But, the proposed system is more simple than existing system. Therefore, we can reduce the system size. Third, this system can remove mechanical moving part by using LEDs. Therefore, a new system is stable.

As a result, we achieved adjustable focus within 2m in one eye.

One of forward plans is to set up the new 3D display system which is consisted of two proposed 3D displays to apply the binocular. Also, we will solve the eye fatigue phenomenon caused by the mismatch between the accommodation and convergence.

6. References

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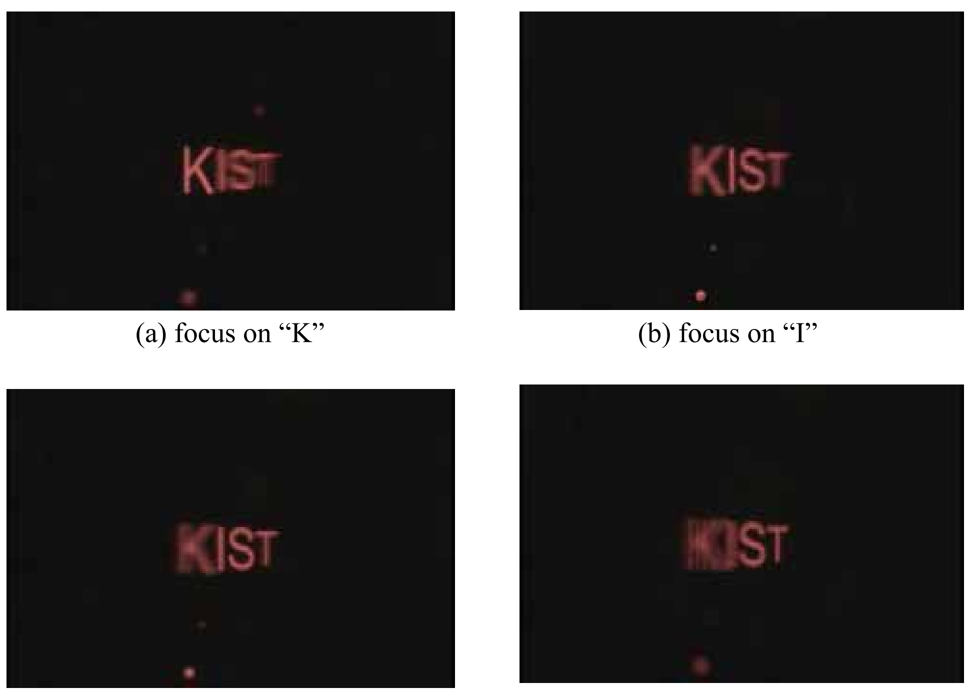

(a) focus on “K”　(b) focus on “I”

(c) focus on “S”　(d) focus on “T”

Figure 3. The results of adjustment focus

(a) focus on 0.25m

(b) focus on 0.5m

(c) focus on 0.9m

(d) focus on 2m

Figure 4. Measurement of blur effect