High-Speed and High-Brightness Color Single-Chip DLP Projector Using High-Power LED-Based Light Sources

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ABSTRACT

This paper proposes a high-speed and high-brightness color projector with a single-chip-DLP configuration that meets the demands for compactness and speed by introducing light sources based on luminescent concentration from LEDs and an optimized optical system. Furthermore, with the unique control circuit of the projector, it actualizes various projection functions.

1 INTRODUCTION

In recent years, the application range of projectors has been remarkably expanded. With the introduction of projectors for advanced displays and measurements, the required functions are not just limited to projection on a fixed flat screen [1]. Such developments have brought out new technical challenges. One of the most important among them is the requirement for increased projection speed. To meet this requirement, it is necessary to increase the updating frequency of videos and reduce the latency from video transmission to projection.

To achieve these objectives, in 2015, we developed a single-chip digital light processing (DLP) high-speed monochrome projector capable of projecting 8-bit images at 1000 fps with a 3-ms delay [2]. We also developed the prototype of a high-speed color projector capable of 947-fps projection [3]. Furthermore, by linking these high-speed projectors with high-speed image sensing, they are being used innovatively in the fields of projection mapping [4-7] and computer vision [8,9].

As shown in the above work, high-speed projectors are expected to have a wide application range, which includes advertisements, man–machine interactions, work support, automobile applications, interiors, and measurements. The potential market size of high-speed projectors is large, and there will likely be a time when low-cost mass production with compactness will be required. Our design concept for high-speed projectors meets such requirements.

High-speed projectors specialized for large-scale events have also been developed recently [10-12]. However, these projectors suffer from a high cost and large size owing to their 3-chip-DLP configurations, which result in complicated optical systems. In contrast, our approach uses light-source modulation for increasing speed in the single-chip-DLP configuration. For this reason, there is a time during which the light source is turned off in each projection frame. Consequently, problems such as high loss in projection power and low brightness were observed.

Fig. 1 Developed projector

This paper proposes a high-speed and high-brightness color projector that incorporates a new high-power light-source module. Furthermore, for use in the various applications mentioned above, this projector is not limited in function to fixed-color projection. It has functions such as monochrome projection with high brightness, flexible modulation control for the digital micromirror device (DMD) and light source in bit units, resolution changing, and external trigger control.

2 HIGH-SPEED, HIGH-BRIGHTNESS COLOR PROJECTOR WITH VARIOUS PROJECTION MODES

2.1 System Configuration

The proposed projector is a single-chip DMD that projects 3 images from red, blue, and green light sources, respectively. Particularly, in order to achieve high brightness, it is essential to increase the power of the light source in the green wavelength region, where the relative visibility for humans is high, followed by the red

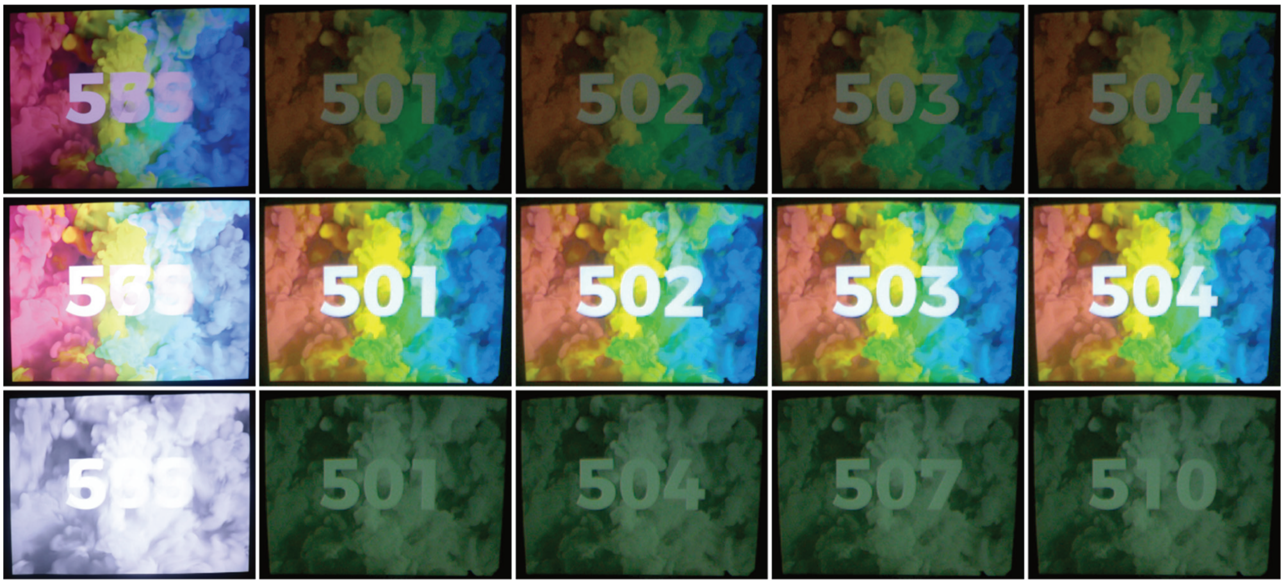

Fig. 2 Projected images captured by DSLR and high-speed camera. Top: 947-fps RGB projection. Center: 500-fps RGB projection. Bottom: 2841-fps monochrome projection.

wavelength region. Furthermore, for high-speed projection, the light source must be capable of high-speed modulation. Additionally, it is necessary to have a compact configuration with a simple optical system. A light-emitting diode (LED)-based light source may be desirable to meet these requirements.

Specifically, it is difficult to satisfy the demand for high brightness by using a light source equipped with only one chip LED. Therefore, this system introduces the high lumen density (HLD) module [13]. This module is based on luminescent concentration resulting from pumping by multiple LEDs. This makes it possible to achieve a high-brightness light source while satisfying the above requirements.

In this system, a green HLD module is used as the green light source. The red light source is extracted from the yellow HLD module by using a bandpass filter. In contrast, the blue light source uses a conventional LED. Color balance can be secured even with a conventional LED for blue light because, compared to green and red, the human eye is less sensitive to the blue wavelength region.

Additionally, the conventional optical system has a small aperture [2] and suffers from low projection brightness. Therefore, we introduced a new optical system optimized for high-speed projectors with a large aperture, the suppression of chromatic aberration, a high resolving power, high light-utilization efficiency, the use of a DMD chip operating at high speed, and the introduced high-power light modules.

Fig. 1 shows the new high-speed projector developed based on the above design. This projector is equipped with the 3 aforementioned light sources and single-chip DMD. Additionally, it is equipped with circuit modules that control these devices at high speed and a high-speed image transmission module.

2.2 Projection Modes

The proposed system is capable of color projection of 8-bit XGA images at a maximum of 947 fps. In this case, single-channel 8-bit images of red, blue, and green are projected sequentially at 2841 fps, which is 3 times the projection speed for one image.

Additionally, it is possible to project monochrome images up to 2841 fps by simultaneously controlling the lighting of the 3 light sources. In this case, the brightness can be increased beyond that of the aforementioned color projection because all the 3 light sources are simultaneously turned on. Such functions are highly useful in applications such as 3D measurement.

Customized projections other than those stated above are also possible with the proposed system. For example, it is possible to project 4-channel color images with red, green, blue, and white. It also can make the control time of DMD and light sources for each bit programmable and switch between different bit-depth images.

The proposed system also has a mode to increase the frame rate by reducing the bit depth and resolution. For example, it is possible to project an 8-bit color image at 1000 fps when the resolution is 1024 × 672. Additionally, the system has a mode for transmitting and receiving trigger signals for performing operations that are synchronized with external sensors and other high-speed projectors.

A dedicated interface with high-speed bandwidth is used for image transmission between a computer and the projector. Consequently, in the case of 1000 fps, the delay in image transmission from the computer to the completion of projection can be suppressed to approximately 2 ms or less.

3 EVALUATION

Fig. 2 shows the 8-bit projected images. In the order from top to bottom, the projection modes were 947-fps RGB projection, 500-fps RGB projection, and 2841-fps monochrome projection, respectively. The leftmost images were captured with an exposure time of 33 ms to demonstrate perception with the human eye. Other images shows the images captured using a high-speed camera synchronized with projection. The monochrome projection results at the bottom show the projection results of every three frames because the imaging rate of the camera was insufficient.

Next, the brightness characteristics are described. The maximum lumen value was 200 and 800 [lm], respectively, when projecting an 8-bit RGB image at 947 and 500 fps. Furthermore, in the 8-bit monochrome projection mode, in which the RGB light sources are turned on simultaneously, the maximum lumen value was 840 [lm] and 3140 [lm] at 2841 and 1000 fps, respectively. The lumen value was 330 [lm] in a previously proposed monochrome high-speed projector [4]. Therefore, we confirmed that high brightness was achieved while maintaining a high speed.

4 CONCLUSIONS

In this paper, we proposed a high-speed and high-brightness projector system. The system was developed with the aim of enabling the use of high-speed projectors in a wide range of applications. Therefore, we aimed to achieve both a high speed and high brightness with LED-based light sources and a single-chip-DLP configuration. This also has added advantages such as the possibility of projection in various modes owing to the highly functional control circuit installed inside the projector. In the future, we plan to develop new applications by using this system.

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