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A High-Brightness and High-Image-Quality Projector Using Laser Light Source

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ABSTRACT

A laser projector with high brightness and high image quality has been realized. Monochromatic laser diodes and a phosphor wheel are combined to generate a large amount of white light. Optimal control of the laser light source solved the problem of image flicker. Laser projectors have become widespread owing to their superior brightness and image quality, and projector applications have expanded significantly.

1 Introduction

The present article relates to a high brightness laser projector that can be used for business, home, signage, event, and other applications. Epson's laser projector generates large amounts of light by using a monochromatic laser light source and a phosphor wheel. The brightness, compactness, and long service life of laser projectors are making them more popular, and their uses are expanding substantially. They are no longer limited to meeting rooms and home theaters. In places like shopping complexes you can see new forms of image expression such as projection mapping and digital art. Epson's "The Invention of a High-Brightness, High-Image-Quality Projector using Monochromatic Laser Light Source (Japanese Patent No. 5928569)" has received the Prime Minister's Prize at the National Commendation for Invention 2021 (sponsored by the Japan Institute of Invention and Innovation). The article describes the invention and reviews related to commercialization of the projector using a laser light source.

2 Development of a laser projector

2.1 Background

There was a growing need for high-brightness, high-image-quality projectors around the time when Epson started developing a laser projector. It was possible to use a plurality of UHP lamps in combination to obtain high brightness, but lamps had a certain life span and had to be replaced regularly, and sometimes a lamp would burn out unexpectedly in the middle of an event. We started developing a laser projector in about 2000. At that time, laser light sources were very expensive, and the three primary colors were just not bright enough. We sought to address this problem by creating a small, high-brightness projector that would offer stunning images and a long operating life yet would be within a commercially affordable price range. We sought to do so by combining a laser light source and other wavelength conversion means to generate the three primary colors of lights.

2.2 Basic structure of the laser light source

Fig. 1 shows the optical structure of the laser projector. The projector uses blue laser diodes as a light source. There are several reasons we chose blue. One is that the blue laser diode can generate a brighter light source at lower power than other colors can. We focused on the fact that yellow light can be generated by irradiating a phosphor material with laser light. White light was generated by combining a blue laser and yellow light produced from the resultant phosphor light and used as projection light.

Since the phosphor will be damaged if a large amount of laser light is continuously irradiated on the same point, we arranged a phosphor in a circular manner on a rotating disk to make a phosphor wheel. As a result, the laser was always focused on a different part of the wheel. The parts of the phosphor wheel could cool down while the laser was not on them, and that helped control temperature increase.

Fig. 1 Optical structure of a laser projector

For the brightness adjustment function required for projectors [1][2], a configuration is used that digitally blinks the laser light source using a frequency signal with pulse widths having lengths corresponding to the desired brightness. Brightness can be adjusted by digitally changing the length of the pulse width. This makes it

possible to adjust the brightness to the optimum level according to the usage environment and the projected image, and to precisely control the brightness of the image when creating one large screen with multiple projectors.

2.3 Technology that eliminates image flicker

Even some projectors that used lamps had an image flicker problem. So, early on in the effort to develop a laser projector, we started testing flicker solutions. Originally, we thought that combining a laser light source with 3LCD technology that generates the image would cause flicker. That's because there was flicker when we combined the light source with liquid crystal displays in lamp projectors. However, flicker occurred with the laser light source alone, so we investigated the causes of the flicker.

Part of the reason for flicker in our laser projectors was that the phosphor was rotating. The thickness of the phosphor could be slightly uneven, or the disk might be warped, or there might be variation in how the phosphor was bonded to the disk. So, as the disk rotated and the laser beam moved over the phosphor wheel, these slight variations in the phosphor wheel caused fluctuations in the intensity of the yellow light.

As mentioned above, we adjust the brightness of laser projectors by controlling the laser elements with a slight pulse, which causes blinking. We can subtly control the relative brightness of the image not only by controlling the intensity of the laser beam itself but by modulating the pulse width to control blinking.

Under some conditions there can be interference between the light and dark cycle of the light from the phosphor wheel and the blinking cycle of the laser diodes under some conditions, that results in a low-frequency component visible to the eye. This causes flicker in laser projectors. After a lot of analysis, we realized that flicker was visible when the difference between the rotation frequency of the phosphor wheel and pulse width modulation frequency of the laser light source is below 20 Hz.

The frequency at which the light intensity output from the phosphor wheel changes depends on the disk's speed of rotation. So, we controlled the pulse width modulation frequency of the laser light source and the rotation frequency of the phosphor wheel so that the gap between these two frequencies would always be at least 20 Hz (Fig. 2).

This eliminated the image flicker of the laser projector and enabled a projector that delivers exceptional brightness and image quality.

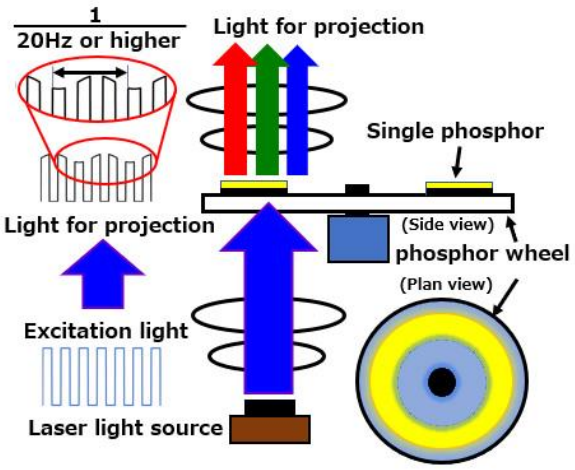

Fig. 2 Mechanism of a laser light source without flicker (Example of frequency difference optimized by setting to 20 Hz or higher)

3 Technologies that enhance the value of laser projectors

The value of laser projectors is enhanced by Epson's unique technology in addition to the basic technology described above. This section describes laser light source control technology and projector control technology that enhance brightness and image quality.

3.1 Laser control technology

Laser light sources are superior in brightness and color control performance to UHP lamps. Epson has a proprietary light source optical system with a mechanism that uses the properties of polarized light to adjust the ratio of blue and yellow to achieve optimal color balance (Fig. 3). In the past, when adjusting the white balance, it was common to weaken either red, green, or blue light with spatial light modulators. The color balance is adjusted by controlling the polarization component of the light output from the blue laser by a quartz retardation plate and adjusting the ratio of blue and yellow. This minimizes the decrease in brightness when adjusting the white balance, and further brings out the performance of the high-brightness and high-image-quality projector.

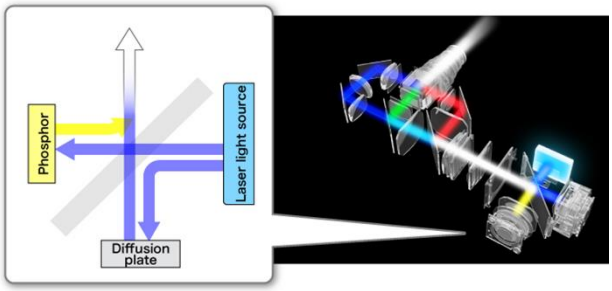

Fig. 3 Optical structure of the laser light source

The projector is also equipped with an optical sensor that detects the amount of light and the color balance of the laser light source. The output of this optical sensor is used to control the color balance so that it remains constant even with aging [3]. Although long operation life is one of the benefits of the laser light source, laser control technologies further enhance this benefit and can be used with confidence while maintaining high image quality.

3.2 Built-in cameras and image processing technology

Multi-projection is used for a wide variety of applications and purposes, to bring a space alive by delivering large, compelling images at events, shopping complexes, and more. The use of multiple projectors gives you the freedom to create huge portrait or landscape images that cover entire walls in large venues, but the installation and adjustment work required to perfect such images usually requires advanced alignment skills. It is necessary to adjust the installation position, adjust the color and brightness due to individual differences, and perform geometric correction. Epson builds cameras and other devices into its projectors to enable auto-adjustment of color, brightness, and various other parameters. When setting up multiple projectors to project a single large, uniform image, the built-in cameras take measurements of the projected images. This data is used to automatically adjust the position, color, brightness, and other characteristics of the projected images. Fig. 4 is a schematic view of the built-in camera unit, and Fig. 5 shows an example of installation adjustment of multi-projection.

The built-in cameras themselves are optimized by individually adjusting them at the factory to match the projected light of the projectors. In addition, Epson has enabled the built-in cameras to accurately measure projection position by using a specially designed projection pattern for measurement purposes. The built-in cameras measure the entire projection surface and its surroundings. The measured data are integrated into one projector to cover the entire multi-projection screen.

The time and effort required to set up cameras to take measurements increases along with the number of projectors. With Epson projectors that have built-in cameras, all users have to do is set up the projectors. Furthermore, the cameras are compatible with various optional projection lenses, so there is excellent scalability. Epson uses a unique algorithm to process the measurements. The measured data are used to facilitate the automatic creation of a single seamless image from tiled images by blending the edges without the need for special equipment.

Fig. 4 Built-in camera unit

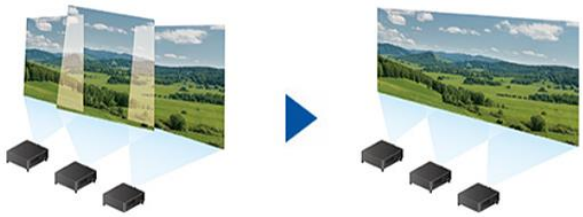

Fig. 5 Example of a multi-projection setup pre- and post-adjustment

4 Applications

A high-brightness and high-image-quality projector has been realized that has a low environmental impact because of its long operating life, small size, and low power consumption. Also, its brightness can be easily adjusted digitally, it can be started up instantly, and it is highly convenient because it can project on the ceiling or floor without any restrictions on the installation angle.

Laser projectors have greatly expanded the applications for projectors. They can be used in offices and schools to project images onto larger screens in large conference rooms and auditoriums. Furthermore, projectors are increasingly being used for signage and spatial design in stores, facilities, and at events. They have opened a new world of visual expression. Projection mapping and other forms of digital art can be used to cover entire spaces with images. Fig. 6 shows some laser projectors and an example of how they can be used.

Fig. 6 Example of laser projectors and their use

There is a unique exhibition called "MORI Building DIGITAL ART MUSEUM: EPSON teamLab Borderless" in Odaiba, Tokyo. About 500 projectors with this technology are used to completely cover an area of 10,000 m^2 with images (Fig. 7). At an exhibition of this scale, the many projectors used must project images at uniform brightness. If not, the images will lack continuity and dynamism, and the immersive experience of being surrounded by images will be lost. The high-precision variable light control of the laser light source has an important role to play in a setting like this.

Fig. 7 EPSON teamLab Borderless, Tokyo © teamLab

Epson has also brought the Fantas Aquarium to facilities such as hospitals and special-needs schools around Japan since 2015 (Fig. 8). The rooms used as venues all differ in terms of brightness, structure, and size. Laser projectors can project bright, high-contrast, and clear images even in a bright room where it is difficult to block out light. In addition, the flexible installation angle makes it possible to easily project onto the ceiling, walls, floor, and other easy-to-see features in rooms of any size, and at an angle that matches the viewer's line of sight.

Fig. 8 EPSON Fantas Aquarium

5 Conclusion

A laser projector with high brightness and high image quality has been realized. Laser projectors have become widespread, and projector applications have expanded significantly. In particular, the use of projectors for lighting, digital signage, and digital art has accelerated in stores, facilities, digital art museums, and at events of various kinds. Using laser projectors has made it possible to provide a richer video experience.

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