Scanning Laser Projection Display and the Possibilities of an Extended Color Space

Christhard Deter and Wolfram Biehlig
JENOPTIK LDT GmbH
Gera, Germany

Abstract

The Scanning Laser Display Technology provides a method capable of representating moving images with superior properties. This technology exhibits three characteristics other projection devices do not have: extremely high contrast, an infinite depth of focus and an enlarged color gamut. Because of this exceptional properties, JENOPTIK laser projection systems are solutions designed for dome projections and simulators.

A multispectral digital camera, developed in cooperation with the Color Research Group of the University of Aachen, can capture images covering the full laser projector color gamut. Therefore the gap between the abilities of capture devices and laser projection is becoming smaller.

Furthermore, other methods like the scientific false-color representation deliver images which require a monitoring device capable to show an extended color gamut, too.

Introduction

JENOPTIK LDT GmbH developed a technology for laser projection displays for the professional market. The applications are orientated to entertainment, simulations techniques and multimedia applications. The direct writing scanning laser beam projection offers some special advantages for these fields of applications. These special advantages are the extremely large depth of sharpness of the pictures, the large color gamut and the saturation of the colors, high contrast and at last but not least no material pixel limitations for the writing beam. These properties will open new domains for the applications on the professional market.

The main focus of the present paper is the extended color space projected by the laser projection device. The extraordinary color gamut creates new possibilities concerning the representation of different image data. The lack of appropriate digital image data for this color space is a current problem. The previous image recording techniques are mostly restricted to the standardised sRGB color space (IEC 61966-2-1). This is due to the restricted color gamut of the TV color space available exclusively until now. A series of possibilities exist in order to remove this deficiency. An essential step in this direction is the development of an extended gamut digital camera (still pictures) developed in cooperation between the Color Reseach Group of the University of Aachen and JENOPTIK LDT GmbH. This prototype of a mobile camera covers practically the complete color gamut of the laser color space (chapter 4.1). Additional possibilities for the supply of convenient picture data are discussed in this paper (chapter 4.2). But first let us start with the inspection of the laser projection system.

1. The Laser Projection System

A schematic diagram of the complete system[1] is shown in Figure 1. Any kind of video or data sources (all known standards) can be connected to the signal input of the video controller unit. The video controller identifies the standard of the input signal and modifies the system. The analog input signals are digitized and buffered in a memory. The next step is the color transformation for color compatibility between the color space for example of the TV and that of the RGB laser.

The laser unit generates the red, green and blue (RGB) beams and supplies them to the modulation stage. The video signal is transformed into optical information for each RGB channel by amplitude modulation. The three laser beams are combined into one collinear beam and coupled into an optical fiber. The fiber delivers modulated light to the projection head, where the beam is deflected successively in a horizontal (polygon scanner) and vertical (galvanometer scanner) direction.

Laser:

A diode pumped mode locked oscillator of Nd:YVO_4 generates a pulse train of about 10 ps with 85 MHz at the wavelength λ=1064 nm. This beam is then amplified to a high power level. One part of it is used for second harmonic generation of 532 nm. The main part of the power pumps a KTA - OPO synchronously to generate a signal wavelength of 1535 nm. This wavelength is mixed with the 1064 nm to the red beam at 629 nm. In a next step the generation of the blue is realized by sum frequency mixing of the rest of 1535 nm with 629 nm to the wavelength 446 nm. Depending of the pump power at 1064 nm the system can deliver RGB in a right color mix for white light of more than 20 W. To scale this power to higher values seems possible.

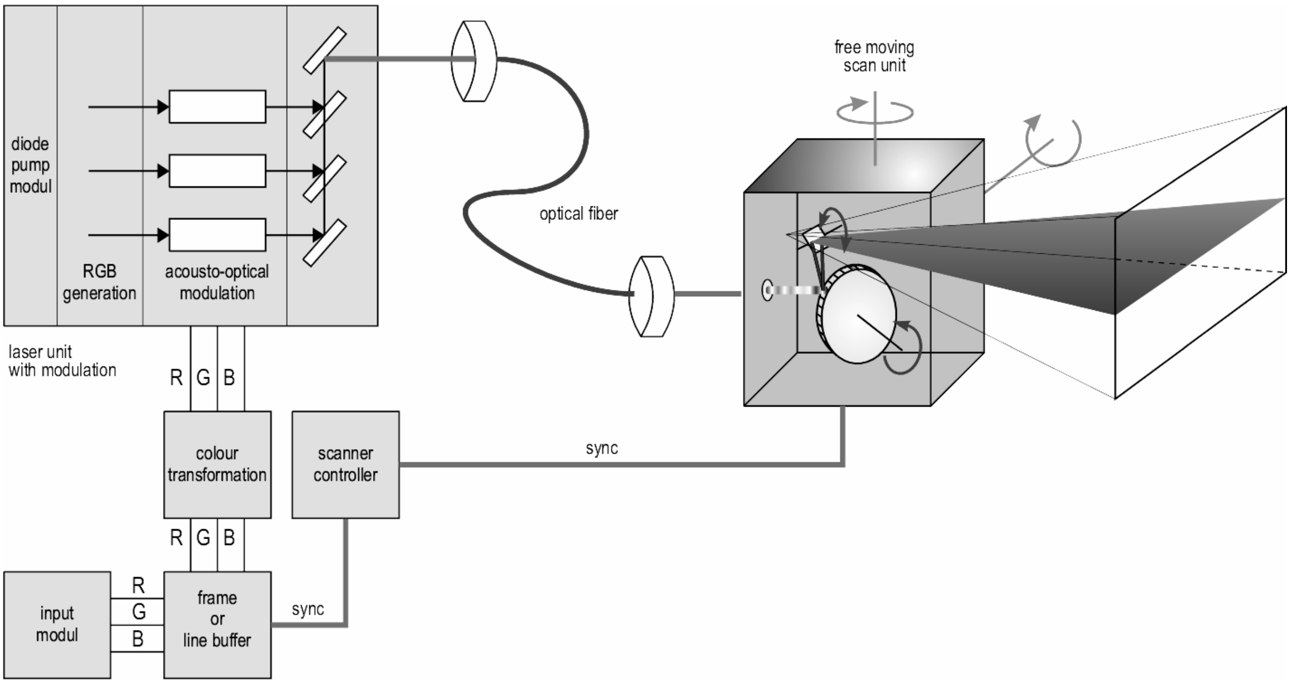

Figure 1. Basic structure of the laser projection display

Modulators:

The modulation part follows directly after the generation of the RGB – beams in the system. The main requirements for the modulation are to realize the video frequency corresponding to the pixel time with an optimum of contrast. We use acousto-optical modulators. The laser beam has to be focused to a small spot in the active area. The spot size and the ultrasonic velocity in the material determine the rise time of the acousto-optical modulator.[4] The diffraction efficiency depends mostly on the acoustic power, the interaction length in the acoustic material, the acoustic wavelength and the laser wavelength and other design questions. Therefore a limiting factor of the modulation frequency is the power density at the waist of the acousto-optical modulator. We achieved a rise time of <10 ns and a diffraction efficiency of the first order for all three wavelengths of about 80% by taking a small waist size and the correct Rayleigh range in the modulator.

Fiber:

After the modulation the three beams are collimated and recombined by dielectric mirrors. This beam contains the full video information and is coupled with a lens (achromat) into a multimode quartz step index fiber with a NA 0.11. The fiber transports the light to the scanner unit. Fiber length can be up to 30 m. The main advantage is to separate the relatively large laser system from the small projection head (scanner unit). This is very important for many applications.

Scanner Unit:

The main parts of the scanner unit are a rotating polygon for the line scan and a galvanometer mirror for the vertical scan of the lines. For the XGA resolution the rotational frequency of the polygon is 2 kHz, which supplies a line frequency of 48,4 kHz. The polygon has 25 facets and the realized scan angle is about 26°. The galvanometer scanner works at 60 Hz and allows a full deflection angle of about 20°. The most critical tolerance for the picture is the variation of the facet apex angle (conical angular error between the facets). For all facets of the polygon an error tolerance of smaller $\pm$ 2 arcseconds is required. Otherwise we will see periods of variation in scan-line spacing at the picture. To compensate this error by electronic means of galvanometer feedback control seems to be possible, but not very efficient. If the facet angle, width and height are manufactured with good quality then the pixel displacement in the line – to – line scan is insignificant because of the high rotating polygon inertia. All the correction and resolution can be done in the range of ¼ pixel.

2. Some Advantage of Laser Projection

Because of it particular functionality scanning laser projection exhibits several extraordinary properties.[1] The scanning laser beam (flying spot) produces a soft transition between the pixels. A scanned picture appears of excellent quality and a seemingly higher resolution. Especially on curved surfaces the extremely large depth of sharpness (5 m to 50 m) and convergence of the colors in each pixel bears the high picture quality. The necessary distortion correction at domed surfaces can be done only by electronical means. If the laser projector is mounted in the dome center the distortion correction is unnecessary.

The kind of laser beam modulation and fiber coupling makes it possible to achieve very high picture contrast values. The On/Off – contrast ratio for the planetarium application is higher than 100000:1. With such a contrast it is possible to project an individual object of the picture (for example a moving moon) on a dark background without visible perceptible scattered light in the frame of the picture. The human eye sees 20 µW of light in green or blue scanned on area of 100 m². This high contrast is also important for simulation techniques. It gives the possibility to make day and night simulation without change of the equipment. Special lenses with an output aperture < 10 mm allow the hiding of the projection head, so that scattered light from the lens is not visible. Furthermore the pictures appear brighter due to the high contrast ratio.

The projector and the RGB - laser can be placed separately. The typical length of the optical fiber, which transmits the laser power, is 30 m. Resulting from this it gets a high flexibility for realization of multi channel projection systems particularly in domes and simulators. Further the fiber solution was demonstrated with a twin fiber per projector for doubled brightness. This method can be used for increasing the resolution of the pictures.

3. Extended Color Gamut

An essential advantage of laser display technology represents the extremly large available color gamut. This color space will be spanned by the three quasi-monochromatic laser primaries, see Figure 2. The RGB laser system produces light with the wavelength 446, 532 as well as 629 nanometers. As the laser wavelength is different from the basic colors of the sRGB, the direct connection of a video source to the laser system gives the viewer a false color perception. Electronic back – transformation restores the color triangle of the laser to that of the sRGB. This ensures full backwards compatibility with any video sources. The stability of the white light D65 is provided from the fixed laser wavelength and power control of the RGB – output. A long term stability < 2% over 8 hours in the output power was achieved by the laser prototypes.

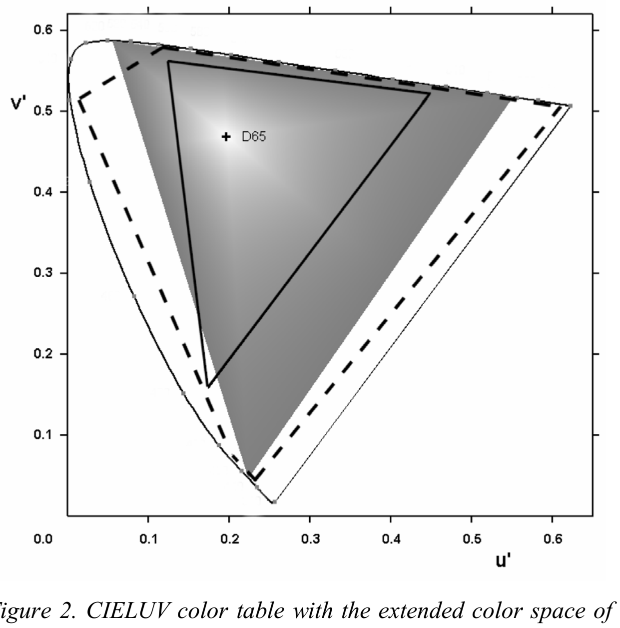

Figure 2. CIELUV color table with the extended color space of the laser projection system (gray triangle). Solid line: sRGB. Dashed line: multispectral camera.

Practical all people have experience with the color palette of television and PC-monitors. But the potential of the essential larger laser color space opens up absolut new posibilities in many different fields. The first experience with pictures containing most saturated colors becomes to a great adventure for everyone. More saturated colors effectuate a much stronger emotional influence to the visitor, which is most important in adversiting industry.

4. Video-Sources Providing an Extended Color Gamut

In this chapter we discuss about the amount of potential available data and images with an extended color gamut, which can be projected with the scanning laser projection device. Till now, a drastic gap between the color facilities of the capture devices and the present laser projection techniques exists. It is true that particular devices exist in special domains. But to our best knowledge in the wide professional region there is no digital camera with more than 4 colors.[2] For example a large multispectral color scanner with a high resolution has been developed by the project VISEUM.[3] This scanner will be used in different museums.

4.1. Extended Gamut Digital Camera

Conventional digital color cameras usually use three color channels with spectral responsivities in the red, green and blue range of the visible spectrum to capture three color signal such as for instance RGB-signals. Due to a number of technical reasons, the channel responsivities differ from color matching functions of the human eye. This results in the fact that color signals of cameras are no exact representations of human color perception. This in turn causes problems of the reproduction of metameric colors. Moreover, the present color camera technology does not cover the whole space of visible colors. Within the project LaserCAVE, a so called multispectral camera with seven narrow band color channels is therefore developed in cooperation between the Color Research Group of the University of Aachen and JENOPTIK LDT GmbH. The advantages of this camera are the essentially increased match with human color perception at reduced camera metamery effects on one hand and the increase of the space of captured colors resulting in the possibility to obtain colors of higher saturation than conventional cameras are able to achieve. Therefore, the captured images are best suited for presenting them on the Laser projection system of Jenoptik LDT GmbH, which offers the display of a wide gamut of colors much better than conventional systems covering the standardized sRGB color space do. Another development of a six channel display with increased color gamut is going on at the Color Research Group in Aachen which can also be considered for higher quality color display of images delivered by the new camera. The display of the improved color images on conventional displays would also improve the color constancy and reproduction quality, yet, without the advantage of the enlarged color gamut. The multispectral camera under development basically consists of a greyscale camera sensor (1029 x 1292) pixels delivering 10 bit signals. In front of the sensor, a fast rotating optical filter wheel with seven narrow band optical filters, each 40 nm wide, is installed, Figures 3 and 4. Synchronized by the rotation of the filter wheel, seven color separations are captured sequentially and provided at the output. With the laboratory model, it is possible to capture a complete set of seven separations within one second. Thus, it is not yet possible to take moving objects, but, compared with other existing nonmobile multispectral camera techiques in the professional field, the speed is essentially improved. Due to the compact design, the camera is mobile and can even be used to capture images outside a studio. According to the number of seven filters, seven images are transferred from the camera to a PC where they are undergoing a number of processing steps to finally derive a high quality color image. Using the captured image of a white reference, the spectral separations are normalized in a first step thus providing color information independent on the light source used to illuminate the scene. In a second step, the spectral distribution of the color stimuli is estimated from the information of the seven separations. Based on the spectral distribution, color values are calculated using the color matching functions of the standard observer. A particular advantage of the availablity of spectral information is the possibility to calculate the color reproduction for any light source (illuminant) which allows to simulate the presentation of the original color image under any illumination conditions at will. Finally, the results are stored in standardized formats using extended color gamut definitions.

Figure 3. Prototyp of the seven channel multispectral camera.

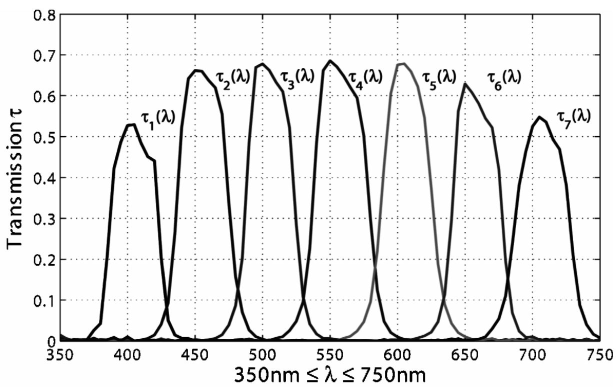

Figure 4. Spectral responsibility curves of the multispectral camera.

More details concerning the multispectral camera can be found in Ref. [5].

Though, the capture of an image takes a second only, processing the image on a PC still requires several minutes. The increase of the speed of the software is an essential matter of further work. Nevertheless, images captured by the system are available already for demonstration.

The development of the seven channel camera within this project aims at the evaluation of the basic capabilities of a seven channel camera technology on one hand and the construction of laboratory models to be used in conjunction with the Laser Display of JENOPTIK LDT GmbH and demonstrate the improved color quality provided by the whole system. As a follow up of the project, it is considered worthwhile and necessary in view of product innovations to find a manufacturer of digital cameras starting a product development of a mobile multispectral camera for professional use.

4.2 Other Video Sources

With help of the new multispectral camera or an other camera with extraordinary color facilities we have the possibility to capture critical and important colors and color differences in a realisitc way, which cannot be captured or presented with conventional devices. For example, in the medical area the realistic representation of blood is very important. With help of the color, the surgeon can get information about the oxygen content of blood and about the actual condition of the patient. Trainees observing a surgery from outside through a monitor might not have the possibility to get the necessary information. Today the multispectral camera is not fast enough for such presentations. But, video cameras with extended color facilities will be available in the professional market in a few years.

Additionally, other data sources exist. First, data sources which can be received by the sampling of original color films. The available color gamut of a color film is essentially larger then the standard sRGB. Usually, the sampled data will be made compatible with the sRGB by gamut mapping. During this procedure, the loss of essential color information is possible. Therefore a lot of convenient image data can be obtained by a new sampling (sampling within an exteded color space) of old color film material.

Second, a visualisation of scientific data can be arranged very well by false color representations. An increasing color space multiplies the diversity of presentable information. For example, a visualisation of astronomical data produces a great visual impact if the color saturation is increased. The extreme contrast of our laser projection devices amplifies this effect.

Third, new options arise also in the artistic area. For example computer generated images: the display of colored fractal structures is very impressive. Such numeric produced mathematic images have in many cases a special aesthetic charm.

Conclusions

The laser projection system was developed for the professional market. The properties of infinite depth of focus, the contrast 1:100000, the high resolution, the large color gamut and the high saturated colors are the advantage of the direct writing laser scanning principle.

The development of the prototype of a seven channel camera used in conjunction with the Laser Display of JENOPTIK LDT GmbH demonstrates the improved color quality provided by the whole system. There exists a lot of different multimedia applications which require recording and representation of an extended color gamut.

Acknowledgment

The development of the multispectral camera is supported by the Department of Education and Science of the Federal Republic of Germany (BMBF).

References

1. Christhard Deter, and Jürgen Kränert, Proc. of SPIE Vol. 3954, pg. 175. (2000).
2. Jacqueline Hewett, Opto & Laser Europe, pg. 17, september, 2003.
3. David Saunders, John Cupitt, Ruven Pillay, and Kirtk Martinez, Colour Imaging -Vision and Technology, ed. by Lindsay W. MacDonald, M. Ronnier Luo, John Wiley & Sons LTD, Chichester, New York, Weinheim, Brisbane, Singapore, Toronto, 1999, pg. 215.
4. C. Chang, Acoustooptic Devices and Applications, IEEE Transactions on Sonics and Ultrasonics, Vol. su-23, No. 1, pg. 2. (1976).
5. Stephan Helling, Enrico Seidel, and Wolfram Biehlig, Algorithms for Spectral Color Stimulus Reconstruction with a Seven-Channel Multispectral Camera, Proc. CGIV 2004, to be published.

Biographies

Christhard Deter has worked for several decades as a leader of important development projects in industries. He received his Ph.D. in technical engineering (summa cum laude) at the Technical University of Chemnitz in 2003 and has been decorated with several high national awards. He receive the ‘Deutscher Zukunftspreis des Bundespräsidenten für Technik und Innovation’ (1997) and the ‚Verdienstkreuz am Bande des Verdienstordens der Bundesrepublik Deutschland’ (2000).

Wolfram Biehlig received his Ph.D. in Theoretical Physics at the University of Jena in 1986. He has worked at this University in the Physical Faculty in different scientific groups. This work has primarily focused on the waveguide theory, the laser theory as well as integrated optics. Since 1999 he has been a member of ‘Laser Display Technology’ in Gera, lead by Christhard Deter. Here he works with the fundamentals of the laser projection (color management, speckle reduction, image quality assessment).