Color Reproduction Complex

1 Introduction

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Topics of the presentation
- the basic terminology in colorimetry and color mixing
- the potentials of an extended color space with a laser projector
- the interplay of different projector settings with the human eye's visual perception

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Currently, different types of projectors are used for digital image representation in planetariums. They include CRT, LCD, DLP or laser projectors. Currently, projectors are compared by their main performance features such as:

- maximum brightness
- maximum contrast, dark light
- resolution of image-providing element, the image source

However, as laser projectors are introduced, another parameter of major significance emerges:

- the presentable color space

Why the issue of presentable color space is closely connected with laser projectors will be explained later on. I will also touch upon the basic terms and relationships of color representation in that section.

2 Fundamentals of Colorimetry

2.1 Color Space

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The color space is a theoretical model indicating all colors which can be projected by a projection device. There are different ways of representing a color space.
One representation option is shown here. All colors are represented in a color table where brightness is indicated orthogonally to the table plane. A three-dimensional model is thus created which is referred to as a color space.

Every device for image capturing (camera), image generation (PC) or image representation (projector) has its own maximal color space which is determined by the primaries of that device. In other words: the color space of a given device is always only a part of the total available color space. Typically, for this reason, there is a mismatch between the source and the projector in a given projection application.
To support the interplay of different devices, there are different standards currently in force. One such standard of increasing significance is sRGB (IEC 61966-2-1).
This standard is based on the “phosphor primaries“ of CRT tubes. One of the next transparencies will be dedicated to the presentable color space of this standard.

2.2 Color Mixing

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The basic principle for representing different colors with projection equipment is additive color mixing. This means that the primary colors – red, green and blue – are mixed with each other to obtain different colors. If the primary colors are mixed in a defined mutual relationship, we will obtain white, typically D65. It is important to note that the presentable space depends on the location of all three primary colors within the color table. The color space is defined by the coordinate positions of the three primary colors. The closer the primary colors are located to the outer edges, the more colors can be represented. Another factor of great significance is the spectral bandwidth of the primary colors. The more narrow-banded (which means saturated) a light source is, the greater will be its presentable color space.

2.3 Color Generation in CRT, DLP, LCD Projectors

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2.3.1 CRT

In the case of CRT, the primary colors are generated using phosphor’s which are excited by an electronic beam. The spectrum of primary colors which we obtain by excitation of phosphor’s is relatively broad, so no saturated colors are generated in this case. Due to three primaries’ location within the color table, the resulting triangular area is relatively small. It corresponds to as little as 33% (per cent) of all colors that can be perceived by the human eye.

2.3.2 DLP (LCD)

DLP and LCD projectors use white light as light source. DLP projectors work with UHP lamps. Colors are generated with the help of color filters in these cases. With single-chip devices, all three color filters are combined into a color wheel, whereas three-chip devices include three chips, each assigned to its own color filter. A color filter also offers but a compromise. If optimized for brightness, it will become more broadband. If you decide for colors with a smaller bandwidth, its brightness will strongly decrease.

2.4 Color Generation in Laser Projectors

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In contrast to conventional projectors, laser projection uses three monochromatic wavelengths. The ability to exactly generate a given wavelength is a specific laser feature. By engineering design measures it is possible to determine a desired wavelength in principle.

Three laser wavelengths are thus generated, spanning a triangular area that covers 66% of all colors perceivable for the human eye. The brilliance of colors increases with increasing color saturation. The images appear to be brighter and the influence of parasitic light is reduced.

2.5 Color Transformation

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The effect of a color transformation will be explained by the example of laser projection.

A color transformation is necessary whenever the primary colors, for example, of a light source do not match those of the display device. In order to transmit identical color information, a given color position must be described by a different relationship of primary colors. This is accomplished by way of mathematical transformation. As an important prerequisite, no color must be changed by this procedure and calculation must be possible in real-time. Fast switching of color transformation proves very useful.

As can be seen from the picture, we have a video source with given color portions. Using color transformation, the image contents are reproduced in an identical pattern that includes other primary color portions.

If color transformation is turned off, the same image will be represented in an unchanged pattern, but with different primary colors. This involves changes in color. Where the primary colors are favorably located, this representation may even provide advantages. What we see is an image view in saturated colors.

2.6 Contrast

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There are a number of parameters with an influence on the final visual impression that a viewer will have of a given picture. Of major significance in this context is the inherent contrast and the dark light level of an image.

The human eye perceives differences in brightness rather than brightness levels. Accordingly, absolute brightness is not of prime importance to the viewer. Hence, a strong image contrast is responsible for high color saturation. In other words: extraneous light in an image reduces the level of color saturation and results in an impaired color impression by the viewer.

In addition, excessively strong contrast produces a quasi 3D-effect in many cases. Where there is a black background, the human eye will be unable to adapt so the image is “suspended“ in the air.

2.7 Influence of Projection Optics

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Another factor of importance for color impression and color resolution is the selected projection optics.

The result decisively depends on how the information of an image source is projected onto a screen surface. On this transparency, you can see the image information as generated on the one hand, and the same image information as projected onto a screen surface by projection optics on the other hand. Projection optics of any kind implies some deterioration in image information and contrast. What finally matters to the viewer are the parameters of the image he or she perceives on the projection screen. Where the contrast is too much impaired by selected optics, this will lead to the effects I have already described before.

For color representation, chromatic aberration is of importance.

3 Extended Color Space from the User's Point of View

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This has been a lot of theory so far. Let us now address some practical issues:

- How can users actually benefit from an extended color space?
- Which data and contents can they use?
- What can be done in the future?

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At the moment, there are no generally established methods for working with an extended color space. However, users of JO LDT laser projectors are able to benefit from the advantages of this projection equipment by adopting the measures described hereafter. Which method should be selected, essentially depends on the type of available data source.

Data sources:

- Using computer-generated data
- Working with preexisting image contents
- Resembling of film material
- Image contents recorded in extended color space

Currently, only laser projectors are able to render strongly saturated colors correctly. Regardless of that, image contents may also be displayed on control monitors. Some color falsifications must be expected in these cases. However, for general assessment of image contents, this is of secondary meaning.

3.1 Using Computer-Generated Data

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A great part of the image contents for planetarium applications are generated on graphic computers. In most cases, natural colors need not be rendered in a realistic manner. Typical image contents are:

- data bases maintained in IGs
- integration of digitized image contents
- visualizations and animations, virtual reality
- representation of graphical effects

3.1.1 Interactive Generation of Image Contents Using a Laser Projector

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Desired image contents are developed by displaying them with the help of a laser projector. This means that the color impression of an image can be assessed online in the process. Color transformation is turned off so the image contents are represented within an extended color space during this procedure. The full laser color space is then available to the user for creating his own image contents. Required image colors can be defined as suitable to fit the viewer's visual impression. Following the generation of an image, this image can only be reproduced in correct colors by the laser projector. Despite that, it can always be viewed on control monitors if minor color shifts are taken into account.

3.1.2 Working With a Desaturated Space (gamut)

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A control monitor is used for development of image contents. No laser projector is required in this case. This version should be given preference where the laser projector is needed for demonstration so it is not always available for development work. For definition of colors, a standard (desaturated) color space (gamut) is selected in this case. Maximum color saturation on the monitor will correspond to maximum color saturation during subsequent reproduction by the laser projector. White will remain white and the relative saturation degree is also preserved. For representation with the laser projector, the internal color transformation function is turned off.

3.2 Working With Preexisting Image Contents

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a) Switching from sRGB to Laser Color Space

Where preexisting image contents are available, you are able to utilize an extended color space with color transformation turned off. This option can be selected for the majority of image contents on display in planetarium applications. The various image contents are perceived as more brilliant and more colorful by the viewer in this case. As the color space is subject to some spreading, there will be a shift in the resulting colors of your image contents. This has no adverse effect in most cases. There is, however, a restriction for human face colors or correct-color representations. For image contents of this type, color transformation must be turned on again to render them in their original colors. Color transformation may be turned on and off during a running planetarium session.

b) Increasing color saturation in laser projector operating software

The operating software provides a controller tool to increase color saturation. This option allows you to prevent hue-shift effects. Whether it should be applied or not, depends on the particular image contents.

c) Mathematical algorithms for color spreading

This option is not yet commercially available, but in the process of development. Color spreading means that calculatory algoriths are specifically designed to achieve a targeted amount in color spread. This technique has a clear potential for increasing color saturation. With critical colors, there may be falsification effects.

3.3 Resampling of Preexisting Color Film Material

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Two more options which may become reality in the near future:

The first option is to digitize preexisting color films in an extended color space. Up until now, digitization has been performed within the CRT color space. Color films cover about 50% of maximum (available) color space. For practical implementation, it will be for color scientists to come up with new gamut mapping methods.

3.4 Image Contents Recorded Within Extended Color Space

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Currently, work is underway to develop image capturing equipment that will allow image contents to be directly recorded in an extended color space. The second step will be gamut mapping matched to the laser gamut. Color transformation at the laser projector will be turned off. Once recorded, these image contents can be represented via suitable data formats.

4 Summary

This paper is a small overview of the issues and aspects which play a major role for practical utilization of extended color spaces. On the other hand, this paper was also intended to give you a general idea of the benefits which users may gain with little extra effort already now from working in an extended color space:

- A laser projector makes the extended color space available to you already now
- You achieve a higher saturation of colors
- And you are able to represent natural colors
- You have clearly better visualization options
- The laser projector brings you very high contrast

The following catchwords suggest a number of scientific applications:

- Make the invisible visible
- Dive into new “depths”

- Higher diversity of presentable information

A second focus of this paper was to make clear that the human eye's perception can be influenced by various technical parameters.
What ultimately matters for the viewer is not a single performance feature of the projector, but the effect which an image on a projection screen has on him or her. The human eye is no measuring device – it just perceives in its own way. The crucial point that makes a projection actually good is whether all projector settings match the eye's perception.