Hi-Fi Soft Proofing Using DLP

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Abstract: The recent development of more sophisticated color management systems and better display technologies has opened the door for soft proofing. For accurate color reproduction, when simulating the appearance of printed images on displays, the gamut of the display must totally enclose that of the print. Hi-Fi printing technologies, using more than four inks, usually have a gamut that exceeds that of conventional three-primary displays. A multiprimary system, using more than three primary colors and introducing Hi-Fi color to displays, could provide a superior gamut and a more accurate color reproduction.

A new type of projectors, based on Digital Light Processing technology, uses a single light source and a filter wheel with transmissive color filters for color reproduction. Together with high contrast and good optical efficiency, this indicates the potential for DLP technology in multiprimary systems. A six-primary system could be obtained by modifying the filter wheel, using six carefully selected color filters for the primaries.

To evaluate the potential for DLP technology in multiprimary systems, the colorimetric performance of a projector has been measured and evaluated. The characteristics of the projector has been used to select new filters for the primary colors, using the volume of the gamut in CIELUV color space as performance criterion. The filters found optimal has been measured together with the projector, yielding a significantly expanded gamut. The results confirm the potential of using multiprimary DLP systems for soft proofing, with the ability to improve the colorimetric performance and accuracy.

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Introduction

The development of more sophisticated color management systems and better display technologies has made soft proofing a realistic alternative, beginning to satisfy the high demands on colorimetric accuracy. Simulating the appearance of the printed image on a display, by using color management and ICC profiles, provides a fast and inexpensive alternative, when the color image workflow is getting more digitalized. By using controlled illumination, frequent calibration of the system and good color management routines, soft proofing can be used for visual control of color accuracy in a reliable way. It is, however, crucial that the gamut of the display totally encloses that of the print, i.e. all available colors in the print must be accurately reproduced on the display. Since the gamut of most displays exceeds that of standard CMYK prints, this issue is usually not a problem.

In printing, the term *Hi-Fi color* refers to different techniques using more than the conventional four inks, that way yielding a gamut superior to conventional printing. For some demanding high quality prints, the CMYK gamut is simply not enough. The most commonly used Hi-Fi printing technique is Hexachrome, a six-color process that adds green and orange to the cyan, magenta, yellow and black. Up to now, Hi-Fi color has mainly been used in expensive high-end systems, but it is becoming more available all the time. Usually the gamut of these high quality prints exceeds that of conventional displays, making soft proofing hard, or impossible, for Hi-Fi printing processes. The gamut of conventional three-primary displays is not sufficient to accurately reproduce all the colors that can be reproduced in the print.

Display systems, such as monitors and projectors, reproduce color by an additive mixture of three primary colors. The gamut of reproducible colors for the display will always be limited within the color triangle bounded by the primaries, when viewed in a 2-D chromaticity diagram. Any color falling outside the triangle will be impossible to reproduce accurately. One way to expand the gamut of a three-primary system is to use purer primaries, closer to the spectral locus, but the gamut will still be limited to a triangle. By using more than three primary colors, introducing Hi-Fi color to displays, the gamut will expand into a polygon, improving the possibilities of covering as much as possible of the perceivable colors. A multiprimary display, using carefully selected primaries, could be used for soft proofing, coping with even the large gamut obtained by high quality Hi-Fi printing. Since modifying monitors into six-primary systems could be an unfeasible task, the focus will be on projection technologies. The larger size of the projected image also gives the additional advantage of being able to view the soft proofs in larger groups.

A six-primary display system, constructed by two conventional LCD projectors and six interference filters, was presented by Ajito et al. (2000). Even with the great optical loss due to the interference filters, a remarkable color gamut was obtained compared to conventional displays. The great importance of improving the contrast of the display was pointed out, as well as the importance of using a system with good optical efficiency. This indicates that projectors based on DLP technology, which provides high contrast and good optical efficiency, should be a promising alternative for multiprimary systems. In an experimental set-up for a six-primary system, two DLP projectors with modified color filters for the primaries could be used, by superimposing their images on the screen. The purpose of this work is to evaluate the colorimetric performance of the DLP technology and investigate its potential for use in multiprimary display systems.

Digital Light Processing, DLP

The heart of the DLP technology is the Digital Micromirror Device, DMD, an optical semiconductor containing an array of thousands of microscopic mirrors. Each mirror, representing a pixel in the image, is mounted on a hinge structure, making it possible to individually tilt it back and forth. By addressing the memory cell below each mirror, it can be electrostatically tilted either towards the projection screen (ON) or away from it (OFF), reflecting the light into an absorbing light trap. The mirrors, which are constantly illuminated by the projection lamp, have the capability of switching more than 1000 times per second. The power of the light is constant; it is the amount of time each mirror projects light that determines the tone value for the respective pixel on the screen. The technique that controls how the mirrors are switched on and off, and consequently the integrated amount of light on the screen, is called pulse width modulation.

For color reproduction, the light from the lamp is in different ways divided into the primary colors, using color filters. High quality applications, such as digital cinema and large vendor displays, use three separate DMD-chips, one for each primary color. DLP projectors for the consumer market, uses only a single DMD-chip, making the system smaller, lighter and less expensive. The single DMD modulates the light for each primary color in succession, and the light then passes through a filter wheel, containing color filters according to the three primaries. When light of different colors falls on the retina fast enough, the individual colors cannot be perceived and the color sensation will be an additive mixture of the three primary colors. The drawback is of course the loss of light, compared to a three-DMD system, since the available light is filtered with the three color filters in succession.

Advantages of the DLP technology, compared to other projection technologies, include the optical efficiency, the high fill factor and its digital nature. Because DLP is based on the highly reflective DMD, and does not require polarized light, it provides a higher optical efficiency compared to the competing LCD technology, which is transmissive and polarization-dependent. In addition, the micromirrors on the DMD-chip are placed with such close spacing, that 90% of the area effectively reflects light on the screen. The result is a seamless picture with higher perceived resolution, compared to LCD with a fill factor of 70%, at best. The digital nature of the DLP technology is another advantage in today's digitalized workflow. In analog displays, the digital image must be converted to analog signals by a D/A converter, introducing noise to the signal. DLP, on the other hand, actually displays the digital image, without any analog step at all. The picture seen on screen is still a digital image, leaving the final conversion to the viewer.

Evaluation of a DLP Projector

In order to examine and evaluate the colorimetric performance of a DLP projector, and to achieve spectral data for the projector to be used for filter selection, the performance of a DLP projector has been measured. The projector, a single-DMD conference room projector (InFocus, 2003), was measured using a spectroradiometer (Photo Research, 2003). All measurements were made in a dark room against a reference white Lambertian reflector. The default values were used for all projector settings, such as brightness, contrast and tint, during all measurements.

From the measured spectral distributions, the CIE XYZ tristimulus values were computed using the 1931 color matching functions for the 2^{o} standard observer. Tabulated data, as well as all colorimetric equations used, were taken from Wyszecki and Stiles (1982). The color triangle for the projector in the CIE 1931 chromaticity diagram is shown in figure 1. As a comparison, the color triangle for a CRT monitor, using the by EBU standardized chromaticity values for the primary phosphors, has been included. Notice how the primaries for the DLP projector are all less saturated than the CRT primaries, resulting in a noticeable smaller gamut.

The surprisingly poor colorimetric performance of this DLP projector is due to the broad banded filters used, resulting in primary colors of low purity. The manufacturer has clearly chosen the brightness of the projector in the trade-off between pure primaries of narrow bandwidth and brighter, broad banded primaries. When using a white light source, the optical loss becomes large if narrow band filters are used, and purer primaries would be achieved at the expense of the brightness of the projector. The spectral transmittance of the color filters used for the primary colors, together with the normalized spectral distribution of the projector lamp, is shown in figure 2. Notice how the filters are very broad banded, with a major overlap for the green and blue filters. The green filter transmits even most of the yellow part of the spectrum.

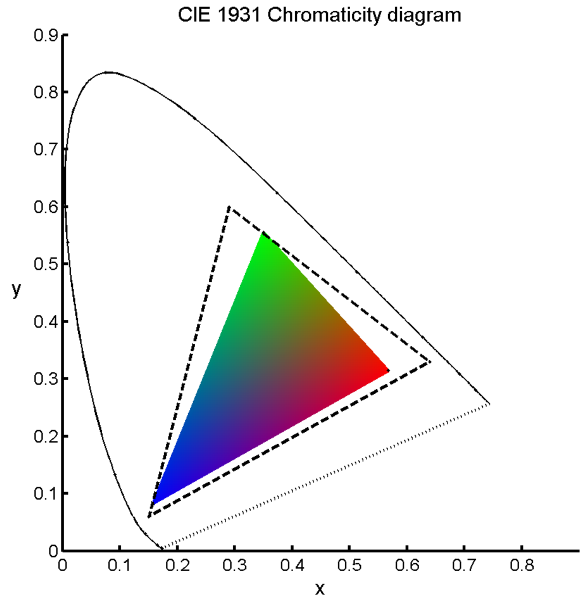

Figure 1. The color triangle for the DLP projector (solid) compared to a CRT monitor, using standardizes primaries (dashed line).

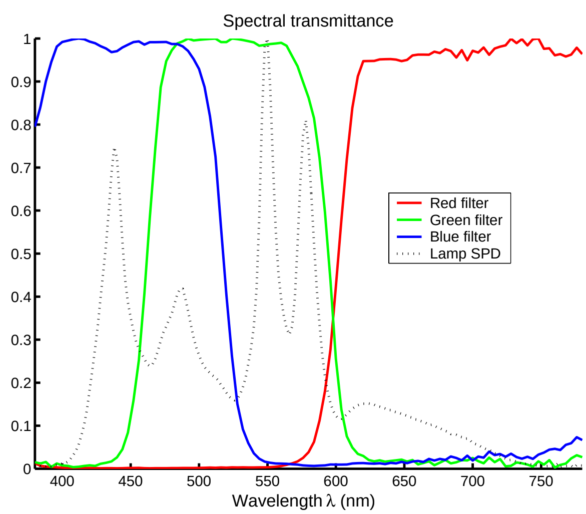

Figure 2. The spectral transmittance of the filters for the three primary colors, together with the normalized spectral power distribution of the lamp.

Filter Selection

The basic idea for an experimental set-up of a six-primary DLP system is to use two projectors, with three different primary colors each, and superimpose the images on the screen. One practical condition for this study is that the first projector should be the already existing one, without modifications. The objective is therefore to find three color filters to be used as primary colors for the second projector. The new filters should complement the existing primaries for colorimetric performance, as well as the spectral characteristics of the projector lamp. The second projector is assumed to be of the same type as the existing one. This way, the measured spectral characteristics for the projector can be used for the filter response calculations.

Practically, it has not been possible to design and use custom made filters for optimal colorimetric performance. The objective is merely to select filters from a set of commercially available filters, which can be easily purchased and used for tests and evaluation. The choice of filter set fell on the Kodak Wratten filters for science and technology. These are thin gelatin color filters, originally designed for photographic use, but also used in a variety of scientific and technical applications. They are inexpensive, readily available and come in a size appropriate for being mounted in front of the projector. Included in the filter set for selection are 27 different Kodak Wratten filters.

The main objective for selecting color filters to be used as additional primaries is to improve the colorimetric performance of the system, yielding an expanded color gamut of reproducible colors. To achieve this, the performance criterion used for the optimization in the filter selection process, must be carefully selected. Previously, the CIE 1931 chromaticity diagram has been used for discussions regarding the color triangle, representing the 2-D color gamut. A straightforward solution would be to use the area of the resulting hexagon in a CIE chromaticity diagram as the performance criterion for filter selection. However, previous results (Kim, 1996) have shown that maximizing the area of the 2-D color gamut in a chromaticity diagram results in an unacceptable decrease of the luminance of the system. In a 2-D projection of color space, the important lightness component is not included, and the selection will be based on saturation only.

A more useful performance criterion for colorimetric filter design should instead be implemented within a 3-D color space, preferably perceptually uniform, such as CIELAB or CIELUV. Since these color spaces are constructed to be perceptually uniform, the volume of a gamut in such space should correspond roughly to the number of different colors that can be perceived by a human observer. Since the CIELUV color space is recommended by the CIE for applications that uses additive color mixtures, the performance criterion for the filter selection is chosen to be the volume of the gamut in CIELUV color space.

The spectral response for the filters is calculated by using their spectral transmittance data, provided by the manufacturer (Eastman Kodak, 1990), and the measured spectral distribution of the projector lamp. From the spectral data, CIELUV values are calculated for each filter, using standard colorimetric equations. The white point of the projector is used as reference white in the CIELUV calculations. For tractability in the volume calculations, the gamut in CIELUV color space is approximated by a polyhedron with planar triangles. For the original three-primary system, the five vertices of the polyhedron are the white- and black point of the projector, and the three primary colors. For the six-primary system, three additional vertices, corresponding to the new primary colors, expand the gamut of the system. From the set of 27 filters, the three filters maximizing the volume of the gamut were found to be the Wratten filters No.12, No.32 and No.44A. Theoretically, they will together contribute to an 81% increase of the gamut, compared to the original system.

Experimental Results

The filters found optimal in respect to the volume of the gamut in CIELUV color space (Kodak Wratten filter No.12, No.32 and No.44A) were purchased and measured in combination with the projector. Due to practical difficulties, it was not possible to have the selected three filters mounted in a special made filter wheel, obtaining a real six-primary system. The performances of the filters were measured by placing the filters in front of the projector, one at the time. This set up corresponds to what can be used as a four-primary system, with the fourth primary provided by an additional projector displaying a gray scale image through a color filter.

The resulting gamut can be seen in figure 3, showing the approximated gamut of the multiprimary system (semi transparent) together with the original gamut (opaque). The measured volume of the gamut in CIELUV color space for the six-primary system yields an increase of 79%, compared to the volume of the three-primary system. All measurements corresponds very well to the previously calculated values, indicating that the tabulated data for the filters are reliable, the previous measurements are accurate, and that the characteristics of the projector has been stable over time. This demonstrates the usefulness and reliability of the method used for filter selection.

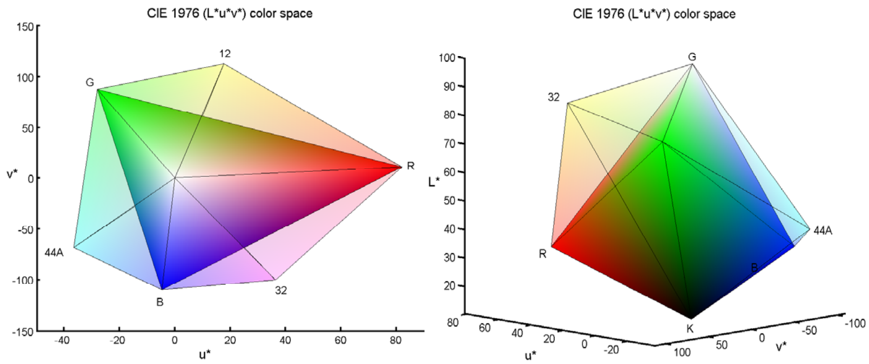

Figure 3. The approximated gamut in CIELUV color space. The opaque polyhedron represents the original three-primary system. The semi transparent polyhedron represents the expanded gamut of the six-primary system.

Discussion and Conclusions

Experiments and measurements have confirmed the potential for DLP technology in multiprimary systems. Even by selecting filters from a rather small set of commercially available filters, a notable expansion of the color gamut was obtained. The superior optical efficiency, brightness and contrast of the DLP technology compared to LCD, makes it the ideal choice for multiprimary projector-systems. The combination of a white light source and highly transmissive color filters reduces the loss of light dramatically, compared to a system with narrow band LCD primaries and interference filters. There is, however, reason to believe that the original three filters, designed for a three-primary system, will not be optimal in a multiprimary system, due to their broad banded characteristics. This was conformed in additional experiments, by using the Kodak Wratten filters for trichromatic color reproduction, as replacements for the original primaries. Together with the selected three filters as additional primaries, this resulted in an increase of the volume of the gamut in CIELUV color space by 137%, relative to the original projector. The conclusion is that, for optimal performance in a six-primary system, the color filters for all six primaries should be narrow-banded and designed for this purpose, prior to using broad banded filters designed for three-primary systems.

For soft proofing, a multiprimary DLP-system could provide a gamut superior to conventional three-primary displays, coping with even the enlarged gamut obtained in high quality Hi-Fi prints. It will not suffer from the unstable color reproduction of the CRT technology, or the variations in color appearance depending on viewing angle, occurring for LCD monitors. The size of a projected image can be substantially larger than for monitors, opening for the possibility of viewing in larger groups.

The application areas for multiprimary DLP systems will not be limited to soft proofing only. The market for digital cinema is rapidly growing. Museums are starting to use multispectral image acquisition of their art, for best possible color accuracy. In today's rapid development in the field of digital color imaging, there will most likely arise a number of new applications with high demands on image quality and accurate color reproduction. With carefully selected filters, a multiprimary DLP system has the potential of satisfying the high demands on color reproduction, offering a gamut far superior to conventional display technologies.

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