

A Content Adaptive Multispectral Projector

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Abstract

A typical video projector has three fixed primaries, typically red, green and blue, and operates by showing a sub-frame consisting of a single color primary at a time. In order to improve the color gamut the projector can cover, one could add more color primaries (e.g. yellow, magenta), however, this would require the projector to be able to operate at higher speeds to show more primaries. Here, we modify the projector for multispectral projection by choosing 3 custom primaries adaptively for each image.

1. Introduction

There are few options available for displaying color with better fidelity than a standard display consisting of three primaries – red, green and blue. One option is to simply use more primaries. In this case, a LCD based display would have more than 3 channels at each pixel, or a projector that relies on time division multiplexing either with a color wheel or individual LEDs for each color channel would need to operate faster to accommodate more channels. However, currently, DLP or DMD (digital micromirror device) based projectors are limited by the speed of these devices to only having 3 primaries. Figure 1 illustrates the limited range of chromaticity values accessible by a standard 3-primary display.

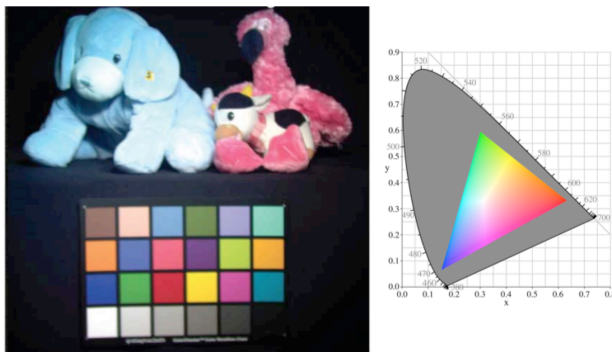


Figure 1: Example of a full spectrum scene, which includes chromaticity values that cannot be represented by the gamut of a red, green, blue color space. The goal here is to develop a

multispectral projector that could adaptively select the gamut within a larger space of available colors to use as primaries.

2. Related Work

Recently, an algorithm for dynamically choosing primaries for each image has been developed. This algorithm factorizes a given image into a set of 3 or 4 optimal custom primaries, where the objective function for the optimization has been computed in the perceptually relevant CIE LAB space.

A prototype has been constructed to attempt to implement this algorithm, as shown in Figure 2. However, in that implementation, the projector could not actually operate fast enough to exceed the human flicker fusion threshold and actually realize the technique to its fullest potential.

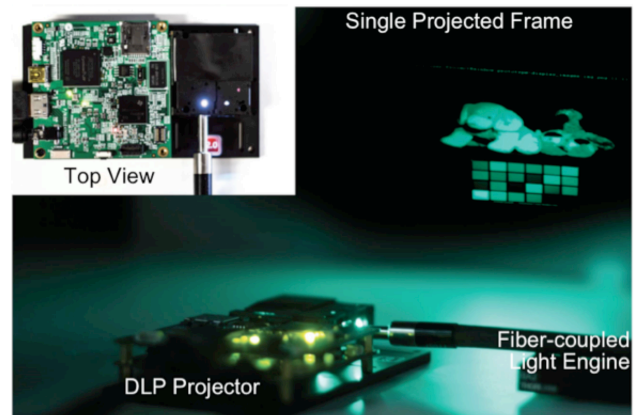


Figure 2: The proposed approach uses a fiber coupled light engine in place of the red, green and blue LEDs. For any given sub-frame, linear combinations of the LEDs in the light engine are turned on to produce a custom primary. In the photo, a green-colored primary is shown. In this way, an existing DLP projector could be modified to show a larger gamut of colors in a content-adaptive way without the need for a faster micro-mirror device for showing more sub-frames.

3. Approach

The approach for building the multispectral projector was to modify an existing DLP based projector. The red,

green and blue LEDs were replaced with a fiber coupled light engine with five primaries. As shown in Figure 3, these 5 primaries span a wide range of chromaticity values.

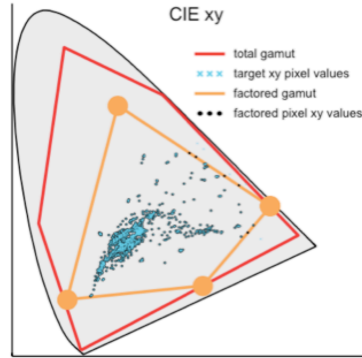


Figure 3: Illustration of the wider color gamut covered by the custom four primaries chosen from linear combinations of the five available color channels in the prototype. Cyan colored data points illustrate the target color values while the dark blue points indicate the gamut-mapped values chosen by the factorization algorithm. These custom four color primaries are then used to display the image on the projector.

However, unfortunately the DMD in the projector is incapable of displaying 5 sub-frames within the short time period available.

In order to make it possible to show 3 or 4 custom primaries, the fiber coupled light engine had to be controlled in a synchronous fashion with the sub-frames of the DMD in order to make the selection of the custom primaries possible.

First, timing waveforms were computed in MATLAB and the sub-frames loaded to the projector through the LightCrafter GUI using jMouseEmu, a MATLAB keyboard and mouse emulator.

Next, a data acquisition device (National Instruments 6343) was used to generate digital waveforms to synchronously activate the various primaries and sub-frames together.

The calibration of the various spectra of the channels was done in previous work (see Figure 4), as was the factorization of the image content.

4. Evaluation

In order to evaluate the prototype, the result was compared with two control test cases.

First, a stock, unmodified projector with 3 red, green and blue primaries was used for comparison. Despite suffering from artifacts (discussed later), the prototype seemed to show better contrast in some colors.

The second comparison test was done on the same prototype projector, but between the 3 custom primaries and the 3 standard primaries. This was a better comparison since both test cases, the experimental and the control,

suffered from the same artifacts (discussed in the next session).

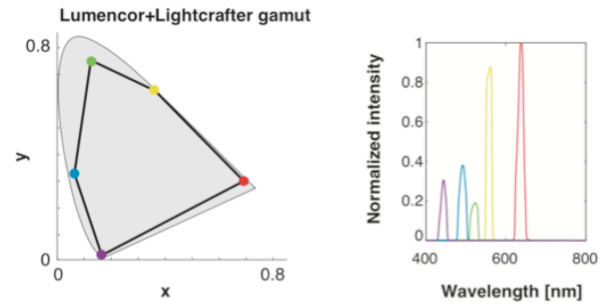


Figure 4: The example spectra produced by the fiber coupled light engine. Each channel produces a narrow spectra for the best possible coverage of all the chromaticity values in the space. Linear combinations of the five channels can be used to produce custom primaries within the convex hull of the five points.



Figure 5: Example image captured of the prototype. Here the camera exposure is longer than the time it takes to load all four sub-frames.

5. Discussion

One of the limitations of this approach is that because both the DMD and the fiber coupled light engine were both controlled by pulse width modulation to get more than simply binary control, there was aliasing between the two different modulation rates. This aliasing resulted in “beating” patterns between the two which were viewable as reduced bit depth and some saturated gray levels in the image, Figure 6 illustrates some of these issues.

One solution to fixing this problem is to simply use an analog light engine so that it wouldn't be possible to have these two frequencies interfere.

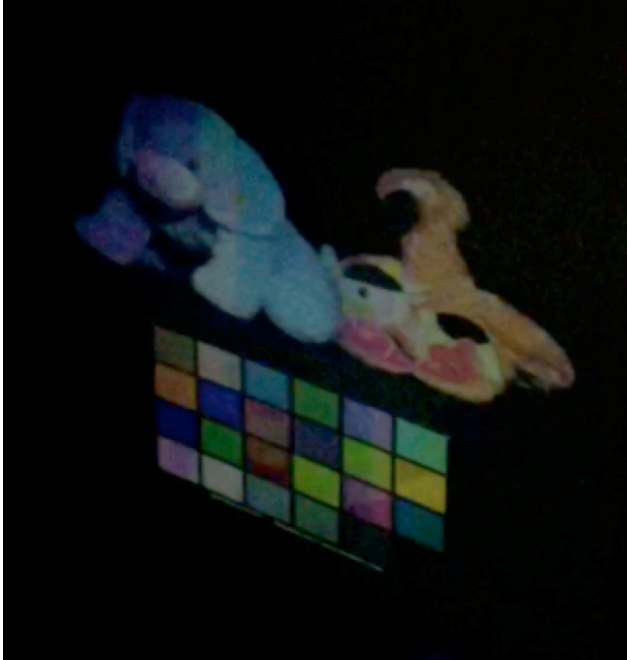


Figure 6: Example of limitations of the current setup. The pulse width modulation frequencies of the DMD and the light engine alias to generate strange patterns that degrade the bit-depth of the image and create artifacts. These could be solved by using an analog-modulated light engine instead.

6. Future Work

There are several items that could be addressed in future work.

First, the issues with the prototype related to the aliasing artifacts as seen in Figure 6 could be eliminated by switching to an analog light engine.

Next, in its current instantiation, the prototype can only work with precomputed and preloaded data sets. Work must be done to optimize the factorization algorithm so that it may work in real time and the interface for controlling the projector and fiber coupled light engine should be implemented in hardware with an embedded system to reduce communication and control latencies.

Finally, for displaying video content, it is likely that the factorization algorithm need to incorporate some smoothness prior to maintain some consistency between the gamut mapping between adjacent frames.

7. Acknowledgments

The author thanks Isaac Kauvar and Gordon Wetzstein for use of figures. Isaac built the first prototype of the projector with the fiber coupled light engine and

LightCrafter projector but they were not synchronized and only good for static speed tests. The remainder of the project was done for the course.

References

- [1] BONNIER, N., SCHMITT, F., BRETTEL, H., AND BERCHE, S. 2006. Evaluation of spatial gamut mapping algorithms. In *Color and Imaging Conference*, vol. 2006, Society for Imaging Science and Technology, 56–61.
- [2] HEIDE, F., LANMAN, D., REDDY, D., KAUTZ, J., PULLI, K., AND LUEBKE, D. 2014. Cascaded displays: Spatiotemporal superresolution using offset pixel layers. *ACM Trans. Graph. (SIGGRAPH)* 33, 4, 60:1–60:11.
- [3] LEE, D. D., AND SEUNG, S. 1999. Learning the Parts of Objects by Non-negative Matrix Factorization. *Nature* 401, 788–791.
- [4] MASIA, B., WETZSTEIN, G., DIDYK, P., AND GUTIERREZ, D. 2013. A survey on computational displays: Pushing the boundaries of optics, computation, and perception. *Computers & Graphics* 37, 8, 1012 – 1038.
- [5] RICE, J. P., BROWN, S. W., ALLEN, D. W., YOON, H. W., LITORJA, M., AND HWANG, J. C. 2012. Hyperspectral image projector applications. vol. 8254, 82540R–82540R–8.
- [6] SAJADI, B., GOPI, M., AND MAJUMDER, A. 2012. Edge-guided resolution enhancement in projectors via optical pixel sharing. *ACM Trans. Graph. (SIGGRAPH)* 31, 4, 79:1–79:122.
- [7] TERAGAWA, M., YOSHIDA, A., YOSHIYAMA, K., NAKAGAWA, S., TOMIZAWA, K., AND YOSHIDA, Y. 2012. Review paper: Multi-primary-color displays: The latest technologies and their benefits. *Journal of the SID* 20, 1, 1–11.
- [8] WAGADARIKAR, A. A., PITSIANIS, N. P., SUN, X., AND BRADY, D. J. 2009. Video rate spectral imaging using a coded aperture snapshot spectral imager. *OSA Opt. Express* 17, 8, 6368–6388.
- [9] WETZSTEIN, G., LANMAN, D., HIRSCH, M., AND RASKAR, R. 2012. Tensor displays: Compressive light field synthesis using multilayer displays with directional backlighting. *ACM Trans. Graph. (SIGGRAPH)* 31, 4, 80:1–80:11.
- [10] ZHANG, X. M., AND WANDELL, B. A. 1996. A spatial extension to cielab for digital color image reproduction. In *Proc. SID*