Properties of Color Variation Across a Multi-Projector Display

Aditi Majumder
Department of Computer Science,
University of North Carolina at Chapel Hill.
majumder@cs.unc.edu

1. Background and Objective

Large area high resolution multi-projector displays have the potential to change the way we interact with our computing environments. These high resolution life-size displays have several advantages over small screen monitors. The high resolution and large field of view makes them extremely useful for visualizing large scientific models. The compelling sense of presence created by such displays make them suitable for creating immersive virtual environments for 3D teleconferencing and entertainment purposes. Several such displays currently exist at Princeton, University of North Carolina at Chapel Hill, University of Minnesota, University of Illinois at Chicago, Stanford, MIT, Fraunhofer Institute (Germany) and United States National Laboratories like Argonne, Sandia and Lawrence Livermore National Laboratories. Recent efforts are directed towards building large displays comprising of 40-50 projectors (Sandia National Labs and National Center for Supercomputing Applications at University of Illinois at Urbana Champaign).

There has been considerable work on geometric registration [7,8] in and, rendering architecture, algorithms and human interface [5.6] for multi-projector displays. But color variation across these display systems still continues to be a difficult problem. Further, there has been work in overlapping projector displays [11] where matching the colors of the overlapping projectors is required. In all such applications understanding the nature of color variation across a multi-projector display can help us make simplifying assumptions that can make the problems of color calibrating multi-projector or overlapping projector displays tractable.

We define a simple parametric space to define the color variation of a multi-projector displays. The parameters are *space, time* and *input.* Given a fixed input and time, the nature of the change of color over space characterizes *spatial color variation.* Similarly, given the same pixel location and input, the change in color with time defines *temporal color characteristics.* Finally, for the same pixel location and time, the color response with changing input defines *input color characteristics.* In this paper, we analyze all three types of color variations for multi-projector displays. We show that multi-projector displays are different from traditional displays in many ways and hence assumptions that can be safely made about other display devices cannot be made for these displays.

2. Results

Projectors are inherently different from the traditional display devices because the physical device space is decoupled from the display space. Hence, projectors can be tiled in a *seamless* fashion when other devices cannot be used for such seamless tiling. As a result, the color characteristics of such tiled displays are unique and needs a separate study. It is important to point out here that we investigate off-the-shelf inexpensive commercial projectors which are more likely to be used for creating large area multi-projector displays.

2.1. Input Characteristics

The property of **channel constancy** assumes that the color projected at a pixel is a linear combination of the color projected by the maximum values of the red, green and blue channels alone when the values of the other two channels are set to zero. This property is indeed true for CRT monitors [1]. This indirectly indicates that for increasing inputs along each channel the chrominance of the colors projected remains constant while their luminance changes in a monotonic fashion.

Unlike CRT monitors, the amount of light projected by most projectors for black (the input [0,0,0]) is not exactly zero. We call this the *black offset.* This makes the color constancy assumption for projectors invalid. As a result, Figure 1 shows that the chromaticity coordinates for increasing input values for the red, green and blue channels are not constant. This shows that projectors do not have channel constancy. A response of an ideal device is shown by the thin red, green and blue lines. However, we show that this black offset can be modeled as a linear constant term.

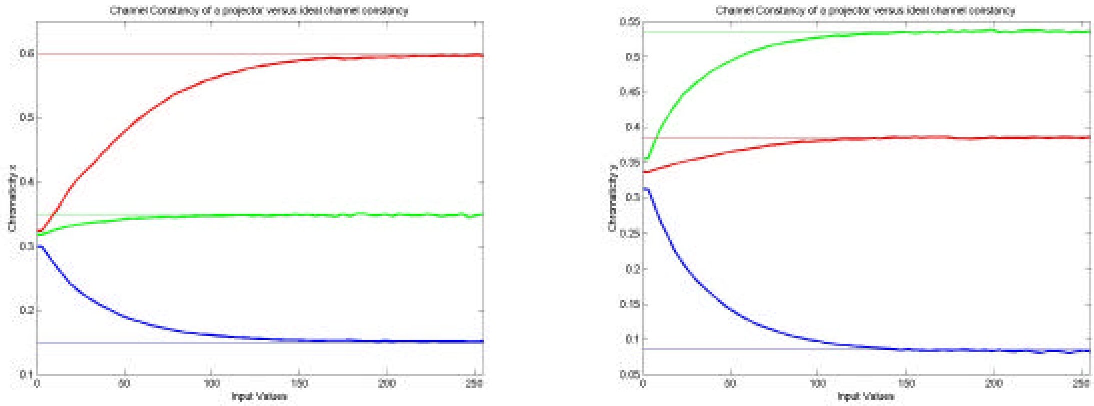

Figure 1: Plot of chromaticity coordinates against input values for the three channels

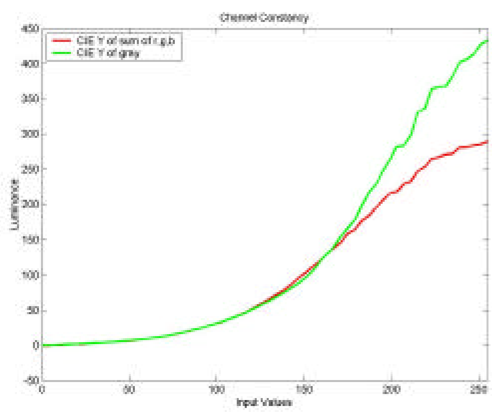

Figure 2 : Channel constancy for DLP projectors with white filter

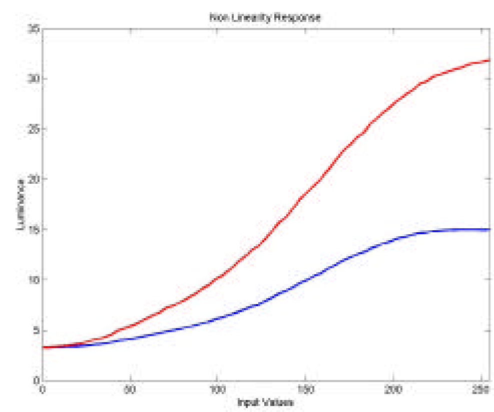

Figure 3 : Non-Linearity Response of Projectors cannot be approximated by a simple power function

Fig 4(a) (left) shows a four projector display when the same color is input to all the pixels. This illustrates how the output color for the same input can differ even within a projector's field of view. Fig 4(b) (right) shows a simple two projector display.

However, it is important to point out here, that some DLP projectors that have a separate white filter for projecting the grays, deviate substantially from channel constancy. The reason for this is not the black offset but the use of a completely different filter which does not have any relationship with the red, green and blue filters to actually satisfy such and assumption. Figure 2 shows this effect. The red line shows sum of the luminance of input *i* of red, green and blue channels measured separately. The green line shows luminance of grey of the same value. The red and green curves in the graph should be coincident in case of a device that follows channel constancy. In case of black offset, there will be a small constant distance between the two curves. The substantial difference as is seen in this plot indicates that this deviation is not due to the black offset.

It has been shown before that the CRT monitors have a **non-linear luminance response** which resembles a power function [1,3,4]. Hence monotonic nature of the response can be easily assumed. We found that the projectors have S-shaped non-monotonic response as shown in Figure 3 (for two channels of a projector). However, the shape of the curve in the monotonic region can be modeled by a power function and an offset.

2.2. Temporal Variation

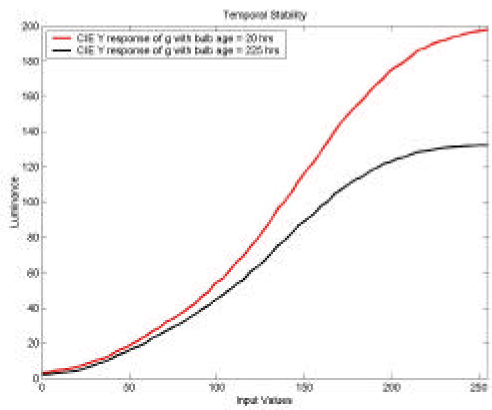

Figure 5 : Change in luminance response of a single channel with bulb age

We investigated how the projectors behave with time at the same spatial location. It has been shown that display devices like CRT monitors or LCD panels [1,2] are temporally stable. But this is not true for the projectors because of the aging of the bulb. As the bulb of the projector ages, there is marked decrease in the luminance response of the projector. For example, Figure 5 shows that after 200 hrs of use, the luminance of a channel can reduce by close to 35%. This indicates that most of the multi-projector display needs pretty frequent recalibration.

2.3. Spatial Variation

The two major components of *spatial color variation* are the color non-uniformity within a single projector's field of view termed as *intra* projector variation (Figure 1a) and the variation across different projectors termed as *inter* projector variations (Figure 1b) [10].

2.3.1. Intra Projector Variations

Nonlinearity Response Characteristics: We found that the non-linear response is not identical at every pixel location. Again, the offset arises from the fact that black is not absolutely zero. Hence, for all practical purposes, one gamma correction look up table can be used to correct for the projector's non-linearity at all locations.

Luminance and Chrominance Characteristics: It is true that most traditional display devices are spatially inhomogeneous. But, the projectors are rather an extreme in this aspect. Our studies show that intra projector luminance variation is large when compared to other display devices. The luminance falls from the center of the projector towards the corner in a radial fashion. We have seen a decrease of about 60% from the center to the edges. It has been shown before for the CRT monitors that the spatial inhomogeneity can be accounted for by a single scale factor [1]. Again, this is not true in case of projectors because of the black offset. Further, it is difficult to find a closed form function dependent on the pixel location for the scale factor. Hence it is difficult to model such large variation from the center to the fringes of the projector's field of view analytically. We have also seen variations in the chromaticity coordinates across a projectors field of view, but they are not as severe as luminance.

2.3.2. Inter Projector Variations

Inter projector variations in luminance arise from not only from intrinsic projector parameters but also from temporal variations in the age of the bulb and the extrinsic parameters like pan, tilt, zoom of the projector. Our studies show that there is a 2-3% difference in the chromaticity coordinates of the projectors of same make, identical extrinsic parameters and same bulb age by about 2-3%. Though this difference in chromaticity coordinates of identical projectors can be ignored for all practical purposes, projectors of different make do differ substantially in chromaticity coordinates of the primaries. The following table summarizes our observation on measuring the average of the chromaticity coordinates for four Sharp XG-EG3000U, two NEC MT-1035 and one nView D700Z setup with identical extrinsic parameters.

Projector Brand	*Red*		*Green*		*Blue*	
	x	*y*	*x*	*y*	*x*	*Y*
Sharp XG-3000U	0.62	0.32	0.33	0.62	0.14	0.07
NEC MT 1035	0.55	0.31	0.35	0.57	0.15	0.09
nView D700Z	0.54	0.34	0.28	0.58	0.16	0.07

3. Originality and Impact

The color variation across different display devices like LCD panels and CRT monitors have been studied before [2,3,4,9], but multi-projector displays have not been studied in the similar fashion till now. This paper discusses about the nature of color variation across large area displays. Thus, this work helps us to

a. classify and identify the origin of different kinds of color variations arising in multi-projector displays
b. be aware of different kinds of simplifying assumptions that cannot be made for such displays.
c. identify some issues to concentrate on while designing better projectors.
d. better understand the issues to be dealt with while designing methods to achieve color uniformity across multi-projector displays.

5. References

[1] D.H.Brainard, *Calibration of a Computer Controlled Color Monitor*, Color Research and Applications, Vol. 14, No. 1, Feb 1989, pp 23-34

[2] Albert Cazes, Gordon Braudaway, Jim Christensen, Mike Cordes, Don DeCain, Alan Lien, Fred Mintzer, Steve L. Wright, *On the color calibration of liquid crystal displays*, SPIE Conference on Display Metrology, Jan, 1999, pp 154-161.

[3] R.S. Berns, R.J. Motta, M.E. Gorzynski, *CRT Colorimetry, Part I: Theory and Practice*, Color Research and Application, Vol. 18, No. 5, Oct 1992, pp 299-314.

[4] R.S. Berns, M.E. Gorzynski, R.J. Motta, *CRT Colorimetry, Part II: Theory and Practice*, Color Research and Application, Vol. 18, No. 5, Oct 1992, pp 315-325.

[5] G. Humphrey and P. Hanrahan, *A Distributed Graphics System for Large Tiled Displays*, Proceedings of IEEE Visualization, 1999.

[6] R. Samanta, J. Zheng, T. Funkhouse, K. Li and J.P. Singh, *Load Balancing for Multi-Projector Rendering Systems*, SIGGRAPH/Eurographics Workshop on Graphics Hardware, August 1999.

[7] R.Raskar, G. Welch, M. Cutts, A. Lake, L. Stesin, H. Fuchs, *The Office of the Future : A Unified Approach to Image Based Modeling and Spatially Immersive Displays*, Proceedings of SIGGRAPH 1998, pp 179-188.

[8] R. Raskar, M.S. Brown, R. Yang, W. Chen, H. Towles, B. Seales, H. Fuchs, *Multi Projector Displays Using Camera Based Registration*, Proceedings of IEEE Visualization, 1999.

[9] M. J. Liaw, H.P.D. Shieh, *Colorimetric Calibration of CRT Monitors Using Modified Bern's Model*, Optik 104, No. 1, 1996, pp 15-20.

[10] A. Majumder, Z. He, H. Towles, G. Welch, *Achieving Color Uniformity Across Multi-Projector Displays*, Proceedings of IEEE Visualization, 2000.

[11] A. Majumder, G. Welch, *Computer Graphics Optique : Optical Superposition of Projected Computer Graphics*, Eurographics Workshop on Virtual Environments, 2001.