Achieving Color Uniformity from Multi Element Display and Printhead Devices

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Abstract

A scalable, low-cost, high-resolution display or printhead may be constructed by tiling multiple smaller displays or printheads.

In this paper approaches and difficulties along creating a low cost scalable display or print head is presented. Challenges achieving a uniform color output by stitching multi-element (displays or printheads) together are presented.

Several different printing and display technologies are studied including LCD and DLP projectors and ink jet print heads.

Introduction

A low cost route to scalable, large high resolution displays or printheads is the stitching of multiple adjacent smaller display or printhead elements to create a larger display area or printhead length. One of the toughest challenges in stitching multi-element devices is avoiding seams and color non-uniformity due to misalignment and variation between constituent elements of the composite device.

This paper focuses on the color uniformity challenges of stitching multiple elements to create larger arrays. Due to manufacturing and design limitations, it is common to observe variation in the density or reflectance produced by sub-elements of the constituent devices. For instance, projectors are known to have higher intensity in their center compared to their edges. For inkjet printheads containing multiple discrete print elements, sometimes drop size variation is observed within the printhead itself.

In the first part of this paper, general optical density or reflectance of each element is studied and a generic characteristic profile is generated. Use of this characteristic profile allows simple, rapid density or reflectance correction procedures for devices with well characterized color behavior. The difficulties in achieving color uniformity from stitching multiple elements with different characteristic profiles are discussed. The paper covers similarities of a range of different display technologies and printing systems.

The second portion of the paper covers common techniques for display and printer calibrations. The effectiveness and accuracy of each method is compared. We show that characterizing primary channels of each element in a multi-element device is more effective than calibrating overall performance of the device to produce a uniform color output. The color uniformity of a number of multi-element devices is compared, and a new approach is proposed to calibrate individual elements to achieve better color uniformity.

Future of Low Cost Scalable Print Heads and Displays

As computing and rendering power increases, there is an increasing need for higher resolution displays, and an opportunity for creating larger display sizes. Higher resolution displays can be achieved using tiled projectors or tiled head-mounted displays [3], [4], [6].

Similarly, in the printing industry, large high resolution printheads are constructed by stitching together arrays of smaller printheads. Hewlett-Packard recently introduced its color MFP Edgeline printer (HP CM8060) using its scalable printhead technology. The technology is based on an array of approximately 0.85 inch long printhead chips that together stretch across the entire page [5].

Figure 1 shows the Edgeline scalable printhead technology that HP introduced based on stitching smaller printhead chips.

Figure 1: HP Edgeline printhead based on tiled printhead chips [12]

In this paper the smaller components (printhead chips or displays) that are used to create the larger component is referred to as elements.

Technologies Used

To generalize the characteristics around creating a multi-element component, 5 different display and printing technologies are studied in this paper. The 5 different technologies are shown in Table 1.

Table 1: Display and printhead technologies used in this paper

Element Technology	Description
CRT Monitor	NEC Accusync 95F
LCD Monitor	Samsung 171N
LCD Projector	Proxima LCD Ultralight LX
DLP Projector	Toshiba TDP-5 DLP
Printhead	InkJet Printhead, 600dpi

Color Uniformity Challenge

In designing a multi-element printhead or display there are several features that can affect the overall displayed or printed image quality [7], [8]. Below is a list of them:

1. Geometric Registration and Positioning Across Different Elements: There has been much work done ([4][9][10]) to enable geometric registration, even for positioned elements.

2. Rendering Architecture and Algorithms: Variation along color channel interactions [1][2] or channel interaction with the screen or the paper ([11]) can cause image quality defects such as non-uniform color density variation.

3. Photometric Uniformity: Due to manufacturing variability and characteristic changes over their useful lifetime, displays and printheads may develop color non-uniformities within elements. The overlap region between the elements commonly appear to have noticeable density variation compared to the non-overlapping areas ([7], [8]). These variations can cause photometric non-uniformity across a large tiled multi-element display or printhead.

Experiment Setup

Data Collection

For all the displays used in this study, the measurements were collected using a Photo Research SpectraScan 650 Spectroradiometer in a dark room with the spectroradiometer at a fixed distance, perpendicular to the center of the display surface. Printhead characteristic was measured using a simple colorimeter device.

As was explained, one of the main challenges in tiling displays and printheads is achieving uniform optical density. Figure 2 shows optical density variation of two black printheads stitched together.

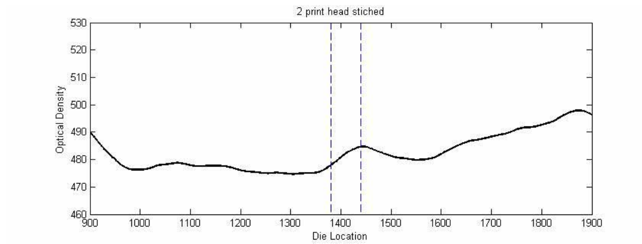

Figure 2: Optical density variation of two printheads with black colorant stitched together (arbitrary scale)

Similar behavior is seen with displays. To characterize this behavior, lightness (CIEL*) variation on the screen is measured at 9 different locations shown in Figure 3. Table 2 shows the lightness variation for the 9 different locations on several displays and along a printhead profile.

The data shows there is a noticeable variation along each primary channel for element which can cause color uniformity defects when the elements are tiled together (Figure 2).

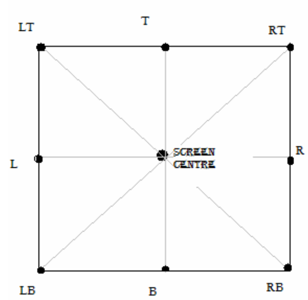

Figure 3: 9 different screen locations used to measured color-uniformity in displays

Table 2: Lightness variation measured in CIEL* for 5 different display and printhead technologies. For displays a white patch and for the printhead black print is used for the measurement ([2])

	Mean ΔL*	Max ΔL*
DLP Projector	9.0066	24.5811
LCD Projector	2.7670	9.1859
LCD Monitor	.51.4	1.4
CRT Monitor	.6	1.2
Printhead	.8	n/a

Colorimeter vs. Densitometer Performance in Measuring Color Uniformity

Colorimeters with sufficient accuracy to measure the variations shown in Table 2 [13] are prohibitively expensive for many tiled array applications. However by making smart choices in device gamut space measurement, a correlation can be derived between the variation in optical density and color uniformity metrics. Densitometers are low cost sensors that can make sensitive measurements of small variations in optical density.

The drawback of using densitometers to achieve color uniformity is that they require a number of geometrical and illuminance corrections before they can be used in a sufficiently accurate manner. If there is interaction between device channels, these effects may be difficult to capture and correct using a densitometer based correction system

Color Uniformity and Primary Channel Characteristics

To correct for any optical density variation it is more accurate to correct primary channels rather than trying to characterize the whole system [7].

It is generally easier and more computationally efficient to apply a smooth transfer function to a 1-D table than a 3-D one, as the table size for equivalent function granularity is 3 x N vs. N^3. Another advantage of correcting primaries rather than characterizing the overall display performance is the full and more accurate range of control over the output of the device. However, to correct the primary channels effectively, careful characteristic setup is required.

Channel interactions can be very important in both displays and ink based printers. In displays [1], especially in LCD technology, the primary channels do interact with each other when two or more primaries are turned on at the same time. Because of this, it is not desirable to adjust a primary without considering its interaction with other primaries.

Similarly, in printers, the dot gain of the individual primaries may be affected by the presence of the additional ink from other primaries, and partially opaque colorants in overlapping ink dots may further complicate the color uniformity response of the system.

To account for any channel interaction, it may be desirable to consider multi channel output for the measurement. Removing this additional signal background and determining the correction signal to apply to each channel can be a significant challenge with this approach

Conclusion

Achieving color uniformity is one of the main challenges when multiple smaller displays or print-heads are stitched together. Densitometers have higher accuracy in observing and correcting the non-uniformity artifact at much lower cost.

To correct for color non-uniformity in a multi-element device, it is important to understand the characteristics of the device. Technically, it is more accurate and easier to adjust the primary channels in the device rather than characterizing and calibrating the output performance.

Designing the settings to measure and correct the primary channels performance require careful setup.

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David Donovan received a BS in Chemistry from the University of California, San Diego (1992), and an MS in Materials Science from Stanford University (2007). He works for the Hewlett-Packard Company on the development of inkjet printheads and inks.