Visiting Scientist from Samsung Advanced Institute of Technology

During the last year at RIT I had a great opportunity to expand my knowledge of color science as well as American culture.

It is well known that color science is an interdisciplinary field which is based on physiology, physics, chemistry, psychophysics, and, if I add one more, computer engineering. Unfortunately, I couldn't recognize this fact until I took Mark's class in psychophysics. It was quite new to me and I had many difficult times understanding but I was delighted to learn many techniques, especially scaling techniques, for the analysis of psychophysical experiments. I am grateful to the wonderful educational and research environment which gave me many helpful experiences for the application of colorimetry and color modeling. However, in many cases, writing reports, programming and doing experiments for classes and my research, consumed more time than I expected, causing me to have a little bit of a phase shift in my daily life style.

I was interested in color appearance models and wing them for certain viewing conditions which produce mixed adaptation states. However before the application of the color appearance models, the adaptation states need to be determined. This work was done using RLAB assuming several adaptation states for monitor and print. The analysis is still going on; I hope that I get meaningful and useful results from this experiment. I'll never forget the night that I shared with Roy in deep discussion of this experiment with "Moose Head" as an energizer.

I have to say thanks to all of the MCSL family: Roy, Mark, Lisa, and Colleen, the students and staff at CIS for their everlasting hospitality, many comments and discussions. Finally, I appreciate my company, SAIT, a great deal for giving me this great chance.

- Heui-Keun Choh

High-Accuracy Colorimetric Characterization of Photographic Films

For the past two years, Dupont's Printing and Publishing Division has been supporting scholarship in the area of colorimetric scanning. This project served as Jim Shyu's master's thesis in color science. Initially, my thought was to take a Howtek D4000 drum scanner (a partial donation by Howtek) and rebuild its optics in order to transform the scanner from an imaging densitometer into an imaging spectrophotometer. I had already evaluated multiple-regression techniques to convert from digital to colorimetric data ad nauseam with only marginally adequate results. A spectral scanner would alleviate metamerism and greatly improve colorimetric accuracy. While laying out Jim's research schedule and listing the various methods of achieving spectral and colorimetric data, I recognized that there was an intermediate method. (I was not alone in this realization; the RIT Research Corporation and R.R. Donnelley both published papers along similar lines.) For coloration systems with fixed sets of colorants, the number of measurements could equal the number of colorants. Each measurement would relate mainly to one colorant. With a priori knowledge of how the colorants optically mixed and their spectral properties, spectra could be estimated from these few measurements. I learned this at RPI where we did color matching by solving three simultaneous equation with absorption and scattering data at three wavelengths. We do this routinely with our CRT colorimetric characterizations. This is a common technique in photographic science where one can convert from integral to analytical density. Rather than an intermediate analysis, it became the focus of Jim's thesis. My preliminary experiments on positive film gave results with equivalent accuracy to abridged spectrophotometers. If we could achieve our objective without rebuilding the scanner, we could use the scanner as a traditional input device for color reproduction or as a colorimetric device. What follows is an edited excerpt from a paper Jim and I will be presenting at the 2nd Color Imaging Conference to be held during November in Scottsdale. Thank you Dupont and Howtek!

- Roy Berns

Colorimetric Characterization of a Desktop Drum Scanner via Image Modeling

Abstract

A desktop scanner was colorimetrically characterized to average CIELAB error of less than unity for Kodak Ektachrome transparencies and Ektacolor paper, and Fuji Photo Film Fujichrome transparencies and Fujicolor paper. Independent verification on spectrally similar materials yielded average ΔE*ab error of less than 2.1. The technique first modeled the image formation of each medium using either Beer-Bouger or Kubelka-Munk theories. Scanner digital values were then empirically related to dye concentrations. From these estimated dye concentrations, either spectral transmittance or spectral
reflectance factor was calculated from an a priori spectral analysis of each medium. The spectral estimates can be used to calculate tristimulus values for any illuminant and observer of interest.

**Results and Discussion**

The $\Delta E_{ab}^*$ histogram for the Ektachrome IT8.7/1 modeling target (as a representative material) is shown in fig. 1 where the predicted CIELAB values are compared with the measured CIELAB values. The histogram of an independent target with 216 patches (6x6x6 digital factorial design) is shown in fig. 2. The table lists the results for the four films analyzed. The 95th percentile was slightly greater than two times the mean of each data set. This technique was very effective for positive films and slightly less effective for photographic papers. In the case of Ektacolor Plus paper, the empirical model relating linearized scanner values (Dr, Dg, Db) to dye concentration had greater residual error than the transparent materials; this was due to the wide-band scanner spectral sensitivities and quantization errors at high concentrations. For the Fujicolor paper, the independent data had large systematic errors. In a post hoc analysis, it was found that the independent target had different dye characteristics than the IT8.7/2 target; as a result, the spectral reconstruction was in error.

![Figure 1. Color difference histogram for Ektachrome modeling IT8.7/1 target.](image1)

<table>
<thead>
<tr>
<th>Material type</th>
<th>Ektachrome film</th>
<th>Fujichrome film</th>
<th>Ektacolor Plus paper</th>
<th>Fujicolor paper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modeling target</td>
<td>Kodak IT8.7/1</td>
<td>Fuji IT8.7/1</td>
<td>Kodak Q60C IT8.7/1</td>
<td>Fuji IT8.7/2</td>
</tr>
<tr>
<td>Avg. $\Delta E_{ab}^*$ of modeling target</td>
<td>0.37</td>
<td>0.41</td>
<td>0.89</td>
<td>0.88</td>
</tr>
<tr>
<td>Max. $\Delta E_{ab}^*$ of modeling target</td>
<td>1.03</td>
<td>1.57</td>
<td>5.17</td>
<td>3.42</td>
</tr>
<tr>
<td>Avg. $\Delta E_{ab}^*$ of independent target</td>
<td>0.71</td>
<td>0.67</td>
<td>2.09</td>
<td>8.75</td>
</tr>
<tr>
<td>Max. $\Delta E_{ab}^*$ of independent target</td>
<td>1.78</td>
<td>1.56</td>
<td>7.29</td>
<td>21.30</td>
</tr>
</tbody>
</table>

**Conclusions**

Applying the well-known technique of converting integral to analytical density to scanner colorimetric characterization yielded excellent results for transparency materials and very acceptable results for reflective materials. The key issues include characterizing the spectral absorptivity properties of the film, narrow-band scanner responsivities, and insuring the image requiring characterization has the same spectral absorptivity characteristics as the model data. This method has the advantage of easily characterizing the scanner for any illuminant and observer of interest, minimizing problems of metamerism. Its one limitation is that the film type must be known and been previously characterized.

- Roy Berns & M. James Shyu

![Figure 2. Color difference histogram of Ektachrome independent verification target.](image2)

- **Munsell Color Science Laboratory**