Modeling a Dye-Sublimation Thermal Transfer Printer

At the recent AIC conference on computer colorant formulation, I presented a paper showing the commonalities between modeling imaging devices such as CRT displays and continuous-tone printers, and coloration systems such as textiles, coatings, and polymers. In general, there are two stages, a nonlinear stage relating user controls to colorant amounts, and a linear mixing stage. To test my general theoretical approach, I attempted to model a dye sublimation printer. Because the results were well within print to print variability, and there is little in the literature on modeling this technology, I am sharing with you a summary of my findings. The analysis was limited to three colorants but would apply equally to four colorant printers.

My original data base was a 5x5x5 sampling (125 colors) of the printer gamut. (I reduced this to about 40 samples at the end. Essentially, one needs to model tone reproduction and colorant interaction.) The samples were measured with a 45/0 spectrophotometer. The Saunderson correction was used to correct for refractive index discontinuity between the dye receiving layer and air:

$$R_{\lambda,\text{internal}} = \frac{R_{\lambda,\text{measured}}}{1 - 0.04 - 0.60 + 0.60 R_{\lambda,\text{measured}}}.$$  

I used the theoretical constants and assumed a refractive index of 1.5. I hypothesized that the transparent form of Kubelka-Munk turbid media theory would model colorant mixing:

$$K_{\lambda} = -0.5 \ln \left( \frac{R_{\lambda,\text{internal}}}{R_{\lambda,\text{substrate}}} \right).$$

For the three color mixing:

$$K_{\lambda,\text{mix}} = c_{c} K_{\lambda,\text{cyan},\text{max}} + c_{m} K_{\lambda,\text{magenta},\text{max}} + c_{y} K_{\lambda,\text{yellow},\text{max}}$$

where the \( c \) terms represent concentration and the absorption properties were based on the maximum density samples. Initially, I calculated concentration by:

$$K_{\lambda} = \frac{1}{\lambda} \int \frac{1}{K_{\lambda,\text{max}}} \lambda$$

as above. In this manner, concentration is a scalar of the maximum spectral absorption and will range between zero and unity. Because the printer is controlled by an imaging board, I had to characterize the relationship between digital counts and concentration. I expected a nonlinear relationship since the printer's three look-up-tables were preset by the manufacturer; they usually bump the contrast to improve image fidelity. Using individual four-level step wedges of cyan, magenta, and yellow, a third-order polynomial was fit. For example, the cyan relationship was:

$$c_{c} = 0.2 d_{c}/255 + 2.4 d_{c}^{2}/255 - 1.2 d_{c}^{3}/255$$

where \( d_{c} \) are digital counts for cyan.

This first model, based on 12 measurements, was used to predict the 125 colors sampling the printer gamut. The average \( \Delta E_{\text{ab}}^{*} \) for D65 and the 1931 observer was 11.6 with a maximum of 21. This unacceptable level of performance was analyzed for systematic errors in prediction. I found that the step wedge polynomials did not predict the dye amounts for mixtures. I suspected that there were colorant interactions due to the equivalent to ink trapping and due to diffusion back onto the donor supply.

In order to model this interaction, I needed to know the exact amount of dye on the paper. Rather than use physical methods such as cross sectioning and microscopy, I used colorant formulation to predict the dye amounts. The Allen algorithm modified for the transparent form of Kubelka Munk was used. I forced tristimulus matches for D65 and the 1931 observer. If the model is correct, the matches should not be metameric. I calculated color differences for illuminant A and found that metameric matches were not predicted; thus the model was an appropriate descriptor of the colorant mixing.

Using stepwise-multiple-linear regression, I modeled the interaction where the concentrations based on the polynomial equations were the independent variables and the concentrations based on colorant formulation were the dependent variables. Twenty eight three-colorant mixtures were used as a data base. (Three-colorant mixtures were used since the Allen algorithm would not be expected to formulate accurate predictions for two- and single-colorant mixtures.) The resulting equations were:

$$c_{y,\text{actual}} = -$$
psychophysically evaluating the compression of color images in different color spaces using the JPEG algorithm. The first part of the thesis will be programming the JPEG algorithm for the Munsell lab's PIXAR system. Then I will prepare a number of test samples for use in the psychophysical experiment. The results of this research will determine if any particular color space is better for the compression of color images. I am excited about this research because the topic is interesting to me and this project combines my background in color science, psychophysics, computer programming and digital imaging.

Hopefully, by this time next year, I will have completed my thesis and earned my Masters degree. At this point, I don't think I will go on and get my Ph.D. Instead, I will look for a research oriented job in some aspect of color imaging, although I have considered the possibility of going into teaching.

-Roy S. Berns

Roy & Mark's Soap Box

Wouldn't It Be Great?

The first commercial instrument for color measurement was developed in the late 1800's by Joseph W. Lovibond. It was a subtractive visual colorimeter known as the Tintometer and modern versions are still in use and commercially available. Color science owes an historical debt to Lovibond for his instrument and the theories that he proposed along with it. To begin to acknowledge this debt, we should examine the context in which Lovibond developed the Tintometer. On page 5 of Lovibond's 1921 book entitled Light and Colour Theories, he explains that he was formerly a brewer. As a brewer Lovibond observed that the finest flavor in beer was always associated with a color technically referred to as "golden amber". He also noted that the color of the beer assumed a reddish hue as its flavor deteriorated. In Lovibond's words "It was these variations in tint that suggested the idea of colour standards as a reliable means of reference." Of course, the world of color science revolves around color measurement standards.

In the United States, the Inter-Society Color Council (ISCC), meets annually. At these meetings, current progress in color science is discussed and advanced through interest groups, project committees, and special symposia. One traditional event at the ISCC meetings is the wine and cheese reception. This reception is usually held on the first evening of the meeting to give everyone a chance to socialize with one another and renew old acquaintances. This past year, the ISCC meeting was held in conjunction with the AIC Silver Jubilee meeting and there were many international guests and several social events. Several participants could be found at a local tavern after most of these social events. These participants echoed one common theme — "Give me a beer." It seems that there was plenty of wine at the official events, but beer was conspicuously missing. This seems odd for a
Standards Laboratory

Who’s Standard? Since its inception the Munsell Color Science Laboratory has been actively pursuing the standard. (Who’s standard, were not quite sure.) At the time of the endowment the laboratory goals were established and the fourth and final goal was to provide secondary standardization services for the color community. We will continue this activity until the service is no longer needed or it interferes with our other goals of education in color science. Not only does this work provide others with needed information but it allows our measurements in other areas of research to be accurate and therefore the research to be reputable.

Currently the Munsell Color Science Laboratory provides 45/0 spectral reflectance factor measurements in the visible region of the spectrum. The material used is either that provided by the user or a set of BCRA (British Ceramic Research Association) Series II tiles. The material is measured commingled with our eight NIST (National Institute of Standards and Technology) primary reference standards. The minor errors in the instrumental measurements of the NIST standards are characterized statistically, and are subsequently corrected for in the measurements of the material in question. The measurements are performed on a commercial instrument, a Milton Roy ColorScan/45, since any small errors are corrected in the optimization to the NIST values. The bandwidth of the instrument is 9.6nm and the measurement interval used is 10nm. In the future we would like to expand our precise and accurate measurement abilities to a diffuse geometry and perhaps multi-angle geometry with our research grade goniospectrophotometer.

It appears that we will be calibrating standards for some time to come due to the lack of SRM’s available through NIST. However, the standard will lose its prestige if the total uncertainty of the calibration values remains stagnant while the precision of the instruments continues escalating.