R·I·T Munsell Color Science Laboratory

2006
Annual Report

Director's Note

Welcome to the 2006 Munsell Color Science Laboratory (MCSL) Annual Report. As you'll see throughout these pages, we've had another busy and fascinating year educating the next generation of color scientists. This would not be possible without the generous support of our research sponsors and other donors. On behalf of all the MCSL students, faculty, and staff, I express our deepest gratitude for your support of our activities and faith in our mission. For those considering donations or project sponsorship, thank you for your interest in our activities and I hope we will be able to collaborate in the future to educate young scientists for the advancement of the field.

We work each day in many different ways to fulfill our mission of education. The following pages briefly describe some of our activities and results from the past year and include highlight stories to provide a sense of the human side of MCSL. We hope you enjoy the report and encourage you to explore our website at <mcsl.rit.edu> to learn more.

As I write this note on New Year's Eve, I am reminded of the lyrics of Auld Lange Syne. This report necessarily makes us think of "times gone by". Franc Grum, the first MCSL Director, set the course for the laboratory with the term nulli secundus and we continue to do the best we can to uphold Franc's vision. Looking forward we see many new challenges and opportunities for the lab. We also have many exciting research and education projects underway and look forward to sharing those results in the future.

We wish you all the best for a wonderful and enlightening 2007.

Mark D. Fairchild
Director, Munsell Color Science Laboratory

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Munsell Color Science Laboratory

The RIT Munsell Color Science Laboratory (MCSL) was established in 1983 through a gift from the Munsell Color Foundation, Inc. Since then MCSL faculty, staff and graduate students have been performing internationally-recognized research in color appearance models, image quality, data-visualization, color-tolerance psychophysics, spectral-based image capture, spectral color rendering and computer graphics, archiving and reproduction of artwork, and other areas of color science and color measurement.

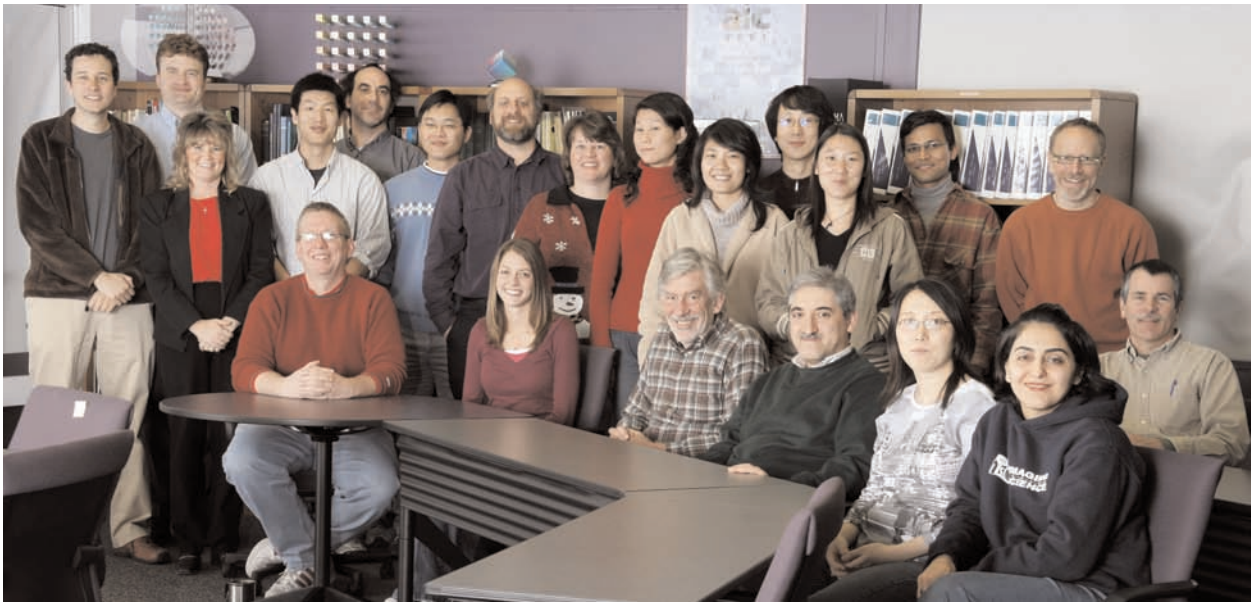
Following the example set by our founders, the guiding objectives of MCSL are …

(1) To provide undergraduate and graduate education in color science,

(2) To carry on applied and fundamental research,

(3) To facilitate spectral, colorimetric, photometric, spatial, and geometric measurements at the state-of-the-art, and

(4) To sustain an essential ingredient for the success of the first three – namely, liaison with industry, academia and government.



Standing: *Lawrence Taplin, Tim Stephany, Colleen Desimone, Changmeng Liu, Ethan Montag, Yu-Kuo(YK)Cheng, Mitch Rosen, Val Hemink, Yang Xue, Ying Chen, Shizhe Shen, Hongqin(Cathy) Zhang, Abhijit Sarkar and Roy Berns.* ***Sitting:*** *Mark Fairchild, Stacey Emery, Rod Heckaman, Mahdi Nezamabadi, Yonghui(Iris) Zhao, Mahnaz Mohammadi and Dave Wyble.*

Graduate Education

RIT offers the only M.S. and Ph.D. programs in color science in the country. More than 80 color science alumni currently work in the field world-wide. Many of them are recognized leaders making significant contributions to the advancement of color science and technology.

Color science graduates are in high demand and have accepted industrial and academic positions in a variety of areas including digital imaging, color instrumentation, colorant formulation and basic and applied research.

Color science students complete their degrees through the Chester F. Carlson Center for Imaging Science within RIT's College of Science. These programs include the M.S. and Ph.D. degrees in Color Science and Imaging Science. In addition, undergraduate students in the Imaging Science B.S. program occasionally complete senior projects or other work experience in the color science field.

See <www.mcsl.rit.edu/education/> for more information on our academic opportunities.

Study of the Image Size Effect on the Color Appearance of Image Reproduction:

Original and reproduced art are usually viewed under quite different viewing conditions. One of the interesting differences in viewing condition is size difference. A colorimetrically characterized projector and LCD are used to reproduce images with very different physical sizes/visual angles. Psychophysical experiments using paired-comparison and contrast matching methods are performed to collect data and develop a multiscale model of the human visual system accounting for the changes of image appearance due to the changes of image size. In a recent experiment, at three different sizes and three levels of contrast and luminance, a total of 63 images of noise patterns were rendered for both displays using three cosine log filters. Fourteen observers adjusted mean luminance level and contrast of images on the projector screen to match the images displayed on the LCD.

Arrangement of scene and equipment in the contrast matching experiment. Mahdi Nezamabadi, a Ph.D. candidate, has been using contrast-matching techniques to develop a multiscale model for rendering of images with very different physical sizes.

Outreach

Outreach is a key educational vehicle for MCSL. In addition to the extensive educational and research resources available for the community at <www.mcsl.rit.edu>, our Summer Short Course and Visiting Scientist Program provide two particularly successful examples of outreach to the color science and technology community.

MCSL Summer Short Course: *Essentials of Color Science*, June 5-8, 2007

Every June MCSL presents this course for people interested in color measurement, specification, control, reproduction, or use. The lectures are designed to form a coherent course that introduces the fundamental concepts of color science, describes various applications, and introduces cutting-edge research areas in color science. Check out the details at: <www.mcsl.rit.edu/outreach/courses.php> or call +1-585-475-6783.

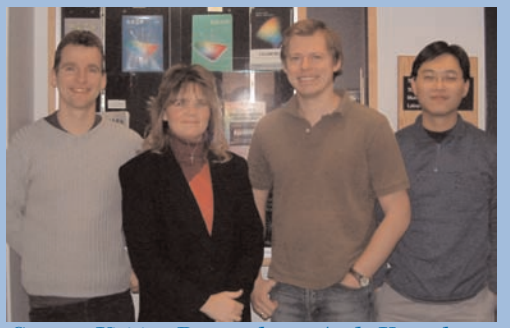
MCSL Visiting Scientist Program

For nearly two decades MCSL has been hosting industrial scientists and engineers for extended periods. These visiting scientists spend 1-2 years in residence at MCSL and work on fundamental research problems of interest to their employer and MCSL researchers. They also have time to participate in formal MCSL course offerings if they so desire and to experience the culture and climate of Rochester and the entire United States.

Feel free to contact any member of the MCSL faculty or staff for more information on becoming an MCSL visiting scientist or send an email to: *desimone@cis.rit.edu* to inquire.

MCSL Thrives on Serving the Color Community:

The Visiting Researcher Program is one way MCSL reaches out locally, nationally and internationally to assist in educating and informing the community about color science. MCSL has enjoyed a steady stream of visiting researchers in residence studying with us. Some companies in recent years included: Oce Technologies, Canon, Fuji Xerox and FOGRA (See the complete list on our website). These researchers come from both industry and educational institutions, and devote from six months up to two years. Their research ambitions and goals lead them to the only internationally-recognized facility devoted to graduate education and research in color science, MCSL. The relationships built through this program are invaluable and last long after the researchers leave.



Current Visiting Researchers, Andy Kraushaar, Philipp Urban and Yu-Kuo Cheng with Colleen Desimone.

After a Visiting Researcher's application is approved and an arrival date is determined, the hands-on process begins. The MCSL Outreach Coordinator, Colleen Desimone, works one-on-one with visitors; she assists them with appropriate paperwork, housing decisions, banking arrangements and transportation options to make their transition smooth. To learn about our visitors, read their stories at: <mcsl.cis.rit.edu/people/vs.php>.

Collaborative Research

MCSL is recognized around the world as a prominent source of leading-edge, interdisciplinary research in color science. MCSL students, faculty, and staff produce scores of journal papers, conference presentations, book chapters, and invited presentations each year (not to mention the occasional text book). Much of this research is done in close cooperation with industrial, government, institutional, or other sponsors. Please see <www.mcsl.rit.edu/about/sponsors.php> to learn about our current and past sponsors.

Recent MCSL research can be generally categorized into four theme areas: Color Measurement & Science, Image Appearance & Modeling, Spectral Color Reproduction, and Color Science for Cultural Heritage. A review of the publications list on the following pages will provide an overview of the range of recent research results. The highlight stories throughout this annual report provide a little more insight into some current and planned projects and activities. As always, much more information on past and current research and publications can be found by visiting <www.mcsl.rit.edu>.

There are many opportunities for new collaborative research projects in support of our mission of providing our students with relevant research topics and the best possible educational experience. Please let us know if your organization is interested in learning more about how to collaborate with MCSL.

Digital Photography Research with Apple:

After more than a decade with the lab, Garrett Johnson moved to the warmer climate of Santa Monica in the spring of 2006 where he joined Apple's professional applications group. Garrett started out in the lab as an undergraduate student working on a senior thesis, moved on to complete M.S. and Ph.D. degrees in the lab, and joined our staff ultimately becoming a research professor. Over that time period, Garrett contributed to approximately 40 MCSL publications (as well as playing countless rounds of golf with color scientists around the world). While we will certainly miss Garrett's day-to-day teaching, mentoring, and research activities, he hasn't completely left the lab. He remains formally connected as a visiting research professor and still participates in some projects and research advising.

We've also been fortunate to develop a collaborative research project with Apple over the past year. Thanks to a generous unrestricted research grant, Apple is helping us further our research activities in digital photography. Currently we are examining techniques for the colorimetric characterization of professional digital SLR cameras to explore the possibilities of making cameras from different manufacturers behave similarly in terms of color accuracy. This research is also supporting the ongoing development of our HDR photographic survey.

2006 MCSL Publications

1.) K. Baum, M. Helguera, J. Hornak, J. Kerekes, E.D. Montag, M. Unlu, D. Feiglin, & A. Krol, "Techniques for fusion of multimodal images: Application to breast imaging," *International Conference on Image Processing*, Oct. 8-11, Atlanta, GA (2006).

2.) R.S. Berns, S. Byrns, F. Casadio, I. Fiedler, C. Gallagher, F. H. Imai, A. Newman, L. A. Taplin, "Rejuvenating the color palette of George Seurat's A Sunday on La Grande Jatte – 1884: a simulation," *Color Research and Application*, **31**, 278-293 (2006).

3.) R. S. Berns, L.A. Taplin, F.H. Imai, E.A. Day, D.C. Day, "A comparison of small-aperture and image-based spectrophotometry of paintings," *Studies in Conservation*, **50**, 253-266 (2006).

4.) R. S. Berns and M. Mohammadi, "Single-Constant Simplification of Kubelka-Munk Turbid-Media Theory for Paint Systems," *Color Research and Application*, in press (2007).

5.) R. S. Berns, "Digital rejuvenation of artwork and its effect on meaning," *Proc. Colour in Fashion and Colour in Culture*, Interim Meeting of the International Colour Association, 54-57 (2006).

6.) Y. Chen, R. S. Berns, L. A. Taplin, "Extending color gamut and improving color constancy for printing through synthetic ink design," *Proc. International Congress of Imaging Science '06*, Rochester, 103-106 (2006).

HDR Image Rendering with iCAM06:

Jiangtao Kuang (known as Willy around the lab) defended his Ph.D. dissertation in the autumn of 2006. His work examined the rendering of high-dynamic-range images for low-dynamic-range displays. He developed and implemented psychophysical techniques to evaluate preference and accuracy for various rendering algorithms. Since completing his dissertation work he has moved on to a position with OmniVision in the silicon valley.

As part of his dissertation, Willy studied the iCAM image appearance model and developed several enhancements based on published research on HDR rendering and color appearance models. His result was a significantly improved HDR rendering algorithm designated iCAM06. More details on this work will be published over the coming year.

The accompanying image shows a linearly-rendered HDR image of Willy in front of The Sentinel (and the sun!) on RIT's campus and a version rendered using his iCAM06 algorithm designed to more accurately simulate human perception of the scene.

7.) M.W. Derhak and M.R. Rosen, "Spectral Colorimetry using LabPQR - An Interim Connection Space," *Journal of Imaging Science Technology*, **50**, 53 - 63 (2006).

8.) M.D. Fairchild, Ed., "Color," *World Book Encyclopedia*, in press (2007).

9.) M.D. Fairchild, "A color scientist looks at video," *3rd International Workshop on Video Processing and Quality Metrics (VPQM)*, Scottsdale, in press (2007).

10.) M.D. Fairchild, "Spectral adaptation," *Color Research and Application*, in press (2007).

11.) M.D. Fairchild, "Color appearance in image displays," *ISCC/CIE Expert Symposium - 75 Years of the CIE Standard Colorimetric Observer*, Ottawa, CIE Pub. x-303:2006, 91-95, (2006).

12.) M.D. Fairchild, "Spectral adaptation: A reason to use the wavenumber scale," *IS&T/SID 14th Color Imaging Conference*, Scottsdale, 314-319 (2006).

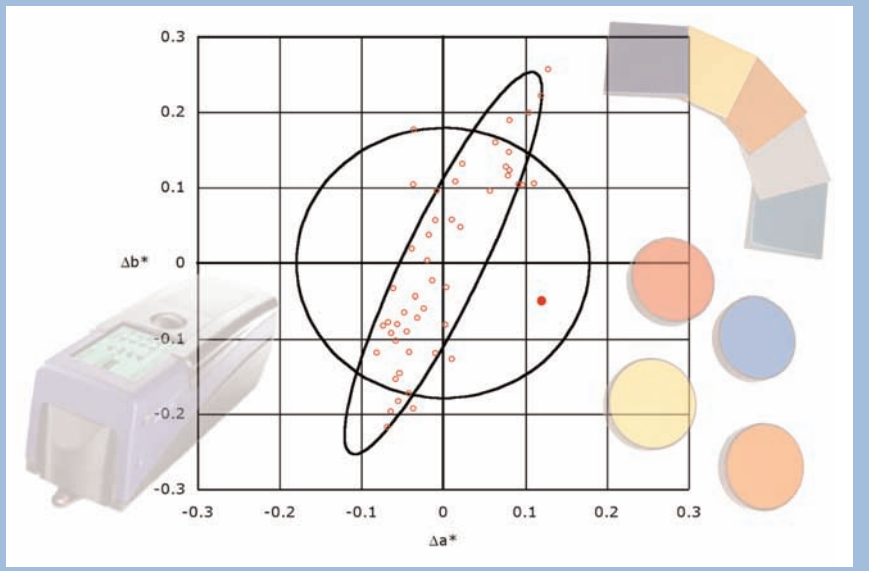
13.) R.L. Heckaman and M.D. Fairchild, "Effect of DLP projector white channel on perceptual gamut," *Journal of the Society of Information Display*, **14**, 755-761 (2006).

14.) R.L. Heckaman and M.D. Fairchild, "Expanding display color gamut beyond the spectrum locus," *Color Research and Application* **31**, 475-482 (2006).

A day in the life at the Munsell Color Science Lab:

It starts out at 8:30 when the doors get opened up and the coffee is made. The members of the faculty, staff and students, not necessarily in that order, start rolling in soon afterwards. Before you know it, the Lab is buzzing with activity. There's classes going on in the Grum Learning Center, research groups working in the labs, and students studying in the Grad Room. Soon, it's time to refuel with some lunch. On any given Monday, Lawrence walks in with four or five pizzas so that you never have to leave the comfort of "home" to get a bite to eat. At $1 per slice, it's a bargain! We always have room to squeeze one more person at our lunchtime table. On Fridays we enjoy family style lunch as the Lab Mom, that's Val, makes grilled ham and cheese, quessadillas or maybe homemade waffles. You can count on Rod, to bring in some tasty desserts to finish off any meal. One thing is for sure, you won't go hungry around here! Lunchtime isn't complete without a game or two of ping pong. That's not to say we all play, but sitting at the lunch table means you are part of the game - since balls can go flying! Unfortunately, all good things have to come to an end - so we push in our chairs and forge on. There's meetings to attend, and work to be done. When it's time to go home, we can all smile as we exit the building, knowing tomorrow is another day.... another great day at the Munsell Color Science Lab.

Color Measuring Instrument Evaluation:



During the summer of 2004, two CIS high school interns, David Borrelli and Carolyn Rudak, performed a five-week test of daily measurements on twelve spectrophotometers. The procedure involved daily calibrations and measurements on all twelve instruments, as well as occasional in-depth evaluation of single instruments. The goal of these measurements was to enable the testing of methods proposed in ASTM E2214, ***Standard Practice for Specifying and Verifying the Performance of Color Measuring Instruments.*** *This practice recommends the use of multivariate statistics over the traditional use of univariate statistics. This recommendation is significant because it represents a change from the use of any of the numerous* ΔE^* *equations. These equations are still very useful for quantifying color difference, but not for instrument performance evaluation.*

The need for a multivariate approach is shown in the image above. These data are actual long-term measurements of a white tile recorded twice daily over five weeks. The open red circles are color differences from the mean value. These data are fit well with an ellipse. The circle shows the equivalent tolerance derived from ΔE^*_{ab}*. The solid black circle indicates a measurement that would be accepted as typical performance using the spherical univariate* ΔE^*_{ab} *tolerance. Details of this and many more recommendations and insights are in two forthcoming* ***Color Research and Application*** *articles, coauthored by Dave Wyble and Danny Rich.*

15.) R.L. Heckaman and M.D. Fairchild, "Effect of DLP projector white channel on perceptual gamut," *Journal of the Society of Information Display* **14**, 755-761 (2006).

16.) J. Kuang, H. Yamaguchi, C. Liu, G.M. Johnson, and M.D. Fairchild, "Evaluating HDR rendering algorithms," *ACM Transactions on Applied Perception*, in press (2006).

17.) J. Kuang, G.M. Johnson, and M.D. Fairchild, "iCAM for high-dynamic-range image rendering," *ACM Proc. 3rd Symposium on Applied Perception in Graphics and Visualization*, Boston, 153, 151 (2006).

18.) J. Kuang, C. Liu, G.M. Johnson, and M.D. Fairchild, "Evaluation of HDR image rendering algorithms using real-world scenes," *Proc. International Congress of Imaging Science '06*, Rochester, 265-268 (2006).

19.) J. Laird and E.D. Montag, "EOTF preferences for LCD televisions: The effect of display brightness and surround illumination on preferred gamma," *Journal of the Society for Information Display* **14,** 9 (2006).

20.) J. Laird, M.Rosen, J. Pelz, E.D. Montag and S. Daly, "Spatio-velocity CSF as a function of retinal velocity using unstabilized stimuli," *IS&T/SPIE Symposium on Electronic Imaging: Science and Technology*, Jan. 16-19, SPIE **6057**, 32-43 (2006) .

Determination of Image Categories:

With the burgeoning number of images that has accompanied the digital photographic revolution comes the problem of how to sort, store, and process the huge numbers of consumer pictures. An understanding of how people categorize and classify photographs can lead to advances in the automation of these processes. In order to determine what the underlying psychological dimensions of image content are, Ken Fleisher has been working on a project sponsored by Lexmark International, Inc. in which he is using multidimensional scaling to analyze the way people judge image content. In one experiment, 32 observers sorted 321 photographic prints containing a very wide variety subject matter into as many category piles as they deemed necessary. Analysis of the data using dual scaling has shown that even though individual subjects may have sorted into as few as 6 and as many as 43 different categories, the underlying psychological representation can be characterized with a very small number of dimensions (3 or 4). In a second experiment conducted online, over 189,000 judgments of image similarity and dissimilarity were collected using the technique of non-repeating random paths. The results show good agreement with the sorting experiment. Using a number of different analytical techniques we hope to identify the dimensions and categories that underlie the relationships among different types of images.

Developing An Imaging Bi-Spectrometer for Fluorescent Materials:

A multispectral imaging system is being developed by doctoral candidate Mahnaz Mohammadi, to reconstruct the reflectance and luminescence components of fluorescent materials. The goal is to minimize the errors caused by the complex and often ignored phenomenon of fluorescence in the digital imaging of artworks. The model is designed based on the filter reduction method in fluorescence colorimetry and UV fluorescence. The unique feature of the developed system is that it will be applicable for imaging of a scene containing both fluorescent and non-fluorescent paints simultaneously.

The figures show images of a painting containing fluorescent and non-fluorescent paints along with a fluorescent calibration target and GretagMacbeth Color Checker as nearly non-fluorescent calibration target under different light sources to separate the reflectance and luminescence components of fluorescent materials. The light sources are tungsten, tungsten plus sharp short-wavelength cutoff filters, and UV-A lamp.

21.) C. Liu and M.D. Fairchild, "The surround color and color matching functions," *IS&T/SID 14th Color Imaging Conference*, Scottsdale, 203-208 (2006).

22.) C. Liu, J. Kuang, G.M. Johnson, and M.D. Fairchild, "Lightness perception on noisy backgrounds considering background frequency and stimulus size," *Proc. International Congress of Imaging Science '06*, Rochester, 464-467 (2006).

23.) Z. Li and R. S. Berns, "Comparison of methods of parameric correction for evaluating metamerism," *Color Research and Application* in press, (2007).

24.) Z. Li and R. S. Berns, "Evaluation of linear models for spectral reflectance dimensionality reduction," *Proc. International Congress of Imaging Science '06*, Rochester, 288-291 (2006).

25.) N. Matsushiro and N. Ohta, "Theoretical Analysis of Subtractive Color Mixture Characteristics," *Color Research and Application*, Vol.31, No.5, 418-424 (2006).

26.) N. Matsushiro, "Theorem and Formula of Color Mixture," *Ph.D thesis*, Chiba University, (March 2006).

27.) M. Mohammadi and R.S. Berns, "Simulated Abridged spectral Fluorescence Imaging," *Proc. International Congress of Imaging Science '06*, Rochester, 111-114 (2006).

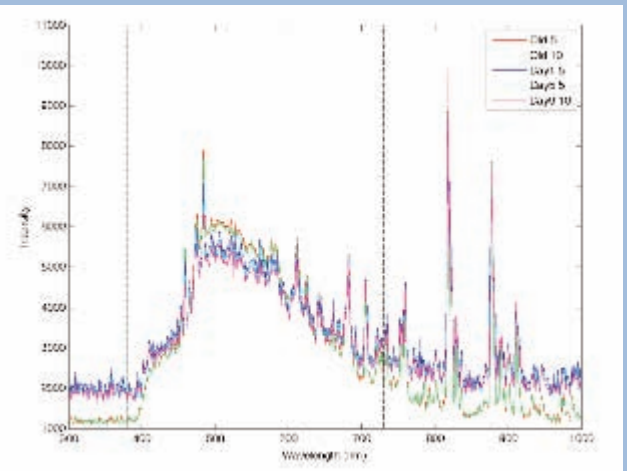
28.) E.D. Montag and M.D. Fairchild, "Fundamentals of human vision and vision modeling," Ch. 2 in Digital Video Image Quality and Perceptual Coding, *CRC Press*, Boca Raton, 45-86 (2006).

29.) E.D. Montag, "Empirical formula for creating error bars for the method of paired comparison," *Journal of Electronic Imaging* **15**, 1, 010502-1-3 (2006).

30.) M. Nezamabadi, R.S. Berns and E.D. Montag, "An investigation of the effect of image size on the color appearance of softcopy reproductions," *Proc. International Congress of Imaging Science '06*, Rochester, NY, 126-129 (2006).

Skin Reproduction:

A nine month project funded by Unilever looking at the reproduction of skin colors recently concluded. Mitchell Rosen worked with student Hongqin Zhang, whom we call Cathy, on evaluating the best ways to ensure that changes in images of faces taken over a span of months can be attributed to variations only in the skin itself.



Flash spectral power distribution variation over 10 days.

One question we wanted to answer was whether the spectral power distribution of the camera flash impacted the results. Like many research projects, the conclusions of this study were not what we would have originally predicted. For example, we were confused for some time over an extraordinary finding that the targets from certain photographs were best at making profiles to predict the color of all photographed targets – better even than profiles from other photographed targets at predicting themselves. We eventually found that in spite of documented flash variations shown in the above illustration, they were small enough that most of the digits in the photographs varied to within 7 digits per channel. Profiles made from these slightly different images just fit the essentially identical data slightly better or worse.

We also compared the use of a Macbeth Color Checker and a simulated target made of skin spectral reflectances for making profiles that predict skin colors. As we expected, the skin targets were relatively poor at making profiles to predict the Macbeth colors. We were surprised, though, that for predicting skin colors, profiles made from the Color Checker performed on average to within .6 of a CIEDE2000 unit from profiles made from simulated skin target. The data for this comparison came from photographs and spectral measurements of multiple skin ethnicities made by Sam Sun during his 2003 doctoral research.

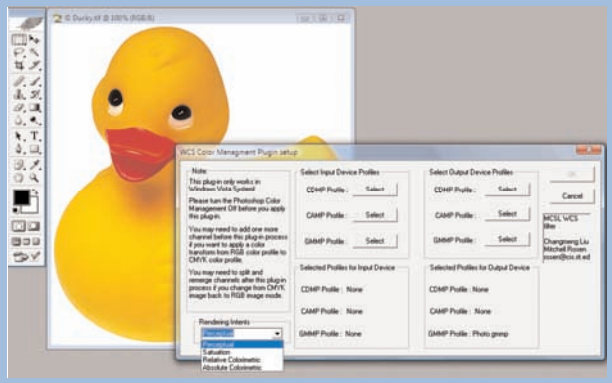
31.) M. Nezamabadi, E.D. Montag and R.S. Berns, "An investigation of the effect of image size on the color appearance of softcopy reproductions using a contrast matching technique," *IS&T/SPIE Symposium on Electronic Imaging: Science and Technology*, Jan. 28 – Feb. 1. SPIE **6493**, in press (2007).

32.) M. Nezamabadi and R. S. Berns, "The effect of image size on the color appearance of image reproductions using colorimetrically calibrated LCD and DLP displays," *Journal of the Society for Information Display*, **14**, 773-783 (2006).

33.) M. Nezamabadi, R.S. Berns, and E.D. Montag, "An investigation of the effect of image size on the color appearance of softcopy reproductions," *Proc. International Congress of Imaging Science '06*, Rochester, 126-129 (2006).

MCSL Looks at Color Management in Windows Vista:

Color management has been a standard part of the major operating systems for close to 15 years. The International Color Consortium (ICC) is the industry forum where the ground rules for device independent color reproduction have been molded and codified. The ICC specification has become an ISO standard and is universally adopted. Even though ICC color management has been in a state of ongoing revision by industry's most outspoken color experts for this past decade and a half, it turns out that many color users are not yet satisfied with the results.



For the past year Munsell has been studying a new alternative to the traditional color management recently released as Windows Color System (WCS), a part of Microsoft's new Vista operating system. Our own alumnus, Michael Stokes, is chief color architect for Vista and has overseen the implementation of a new, in many ways more modern approach to color management. Unlike traditional ICC, WCS uses stripped-down device measurement-based profiles, makes color matches in the CIECAM color appearance space and allows real-time modification of gamut matching techniques. Color management practiced this way is far more computationally burdensome than typical ICC but allows for dynamic color matching methods.

Mitchell Rosen and our student Changmeng Liu have taken the lead in the WCS investigations. As a research tool, they have implemented a Photoshop plug-in that allows the user to use combinations of WCS and/or ICC profiles and to specify the various parameters to WCS color management. The plug-in is freely available to the public and can be downloaded from the Munsell web page.

34.) N. Ohta and A. R. Robertson, "Colorimetry, Fundamentals and Applications," *John Wiley & Sons*, (Nov 2006).

35.) M.R. Rosen, F.H. Imai, Y. Chen, L.A. Taplin and R.S. Berns, "Desktop spectral-based printing," in N. Ohta and M.R. Rosen, eds., Color Desktop Printer Technology, *CRC Press*, Boca Raton, 249-268 (2006).

36.) M.R. Rosen, "Color Theory," in Focal Encyclopedia of Photography, 4th Ed., Edited by M. Peres, *Focal Press*, in press (2007).

37.) M.R. Rosen, "Spectral Imaging," in Focal Encyclopedia of Photography, 4th Ed., Edited by M. Peres, *Focal Press*, in press (2007).

38.) M.R. Rosen and M.W. Derhak, "Spectral Gamuts and Spectral Gamut Mapping," *Proc. of SPIE* **6062** (2006).

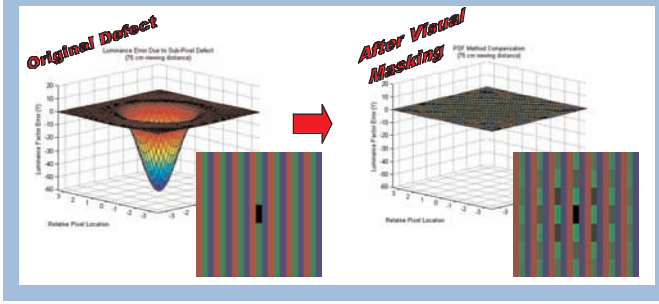
39.) M.R. Rosen and N. Ohta, Editors, "Color Desktop Printer Technology," *CRC Press*, Boca Raton (2006).

40.) M.R. Rosen, "New Windows Color Management System," *Proc. of IGGC* (2006).

41.) M.R. Rosen, "Color Management," in Color Desktop Printer Technology, Edited by M.R. Rosen and N. Ohta, *CRC Press*, Boca Raton, 237-247 (2006).

Visual Hiding of Defects

A desire to better understand the basics of imaging and color science is what led Joe Stellbrink, of Hewlett Packard, to MCSL. Further interest in image appearance modeling resulted in a summer graduate project investigating methods for visually hiding defects in pixelated displays. A visual experiment was performed to compare two previously published methods to a third, newly developed method, which incorporated a simple model for the visual masking characteristics of the human visual system. As shown in the figure below, the estimated luminance factor error produced by a sub-pixel defect (left) can be completely hidden at typical viewing LCD monitor viewing distances by using neighboring sub-pixels to compensate for the defect (right). The use of the iCAM Image Difference Model to predict relative performance of these methods was also explored. By incorporating a simple masking model into the default iCAM model, the general differences in defect hiding effectiveness between the three methods were predicted with reasonable accuracy. Joe returned to HP with a M.S. in Color Science, ready to apply the fundamentals of imaging and color science acquired at MCSL.



42.) A. Stockman, E.D. Montag and D.J.Plummer, "Paradoxical shifts in human colour sensitivity caused by constructive and destructive interference between signals from the same cone class," *Visual Neuroscience*, **23**, 471-478 (2006).

43.) S. Tsutsumi, M. Rosen, and R. S. Berns, "Spectral reproduction using LabPQR: Inverting the fractional-area-coverage-to-spectra relationship," *Proc. International Congress of Imaging Science '06*, Rochester, 107-110 (2006).

44.) S. Tsutsumi, M.R. Rosen and R.S. Berns, "Spectral Color Management using Interim Connection Spaces based on Spectral Decomposition," *Proc. of 14th Color Imaging Conference*, 246-251 (2006).

45.) P. Urban, D. Schleicher, M.R. Rosen and R.S. Berns, "Embedding non-euclidean color spaces into euclidean color spaces with minimal isometric disagreement," *JOSA A*, in press (2007).

46.) D.R. Wyble and D.C. Rich, "Evaluation of Methods for Verifying the Performance of Color-Measuring Instruments." Part I: Repeatability, *Color Research and Application*, in press (2007).

47.) D.R. Wyble and D.C. Rich, "Evaluation of Methods for Verifying the Performance of Color-Measuring Instruments. Part II: Inter-instrument Comparison," *Color Research and Application*, in press (2007).

48.) D.R. Wyble, "Comparison of Methods for Verifying the Accuracy of Color Measuring Instruments," *Inter-Society Color Council 75th Annual Meeting*, Ottawa, Canada, May 14-15, 2006.

49.) D.R. Wyble and M.R. Rosen, "Color Management of Four-Primary DLP Projectors," *Journal of Imaging Science Technology* **50**, 17 - 24 (2006).

50.) H. Zhang and Montag, "How well can people use different color attributes?," *Color Research and Application*, **31**, 445-457 (2006).

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54.) Y. Zhao, R. S. Berns, L. A. Taplin, "Image segmentation and pigment mapping in spectral imaging," *Proc. International Congress of Imaging Science '06*, Rochester, 294-297 (2006).

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Kenneth Fleisher, *mc*
John Grim, *mc*
Rodney Heckaman, *pi*
Jiangtao Kuang, *pi*
Chengmeng Liu, *pi*
Mahnaz Mohammadi, *pi*
Mahdi Nezamabadi, *pi*
Jim Proper, *pi*
Abhijit Sarkar, *mc*
Shizhe Shen, *mc*
Yang Xue, *mi*
Hongqin Zhang, *pi*
Yonghui Zhao, *pi*

Visiting Researchers

Yu-Kuo Cheng, *University Taiwan*
Nobuhito Matsushiro, *Oki Data*
Rafael Nicolas, *University J. Monnet*
Shohei Tsutsumi, *Canon Inc.*
Philipp Urban, *University Hamburg*
Xiaoxia Wan, *Wuhan University*

Alumni of Graduate Programs

2006
Yongda Chen, *pi*
Zhaojian Li, *mc*
Joe Stellbrink, *mc*

2005
Maxim Derhak, *mi*
Tim Hattenberger, *mi*
Jim Hewitt, *mi*
Justin Laird, *mc*
Erin Murphy, *mc*
Yoshio Okumara, *mc*
Michael Surgeary, *mi*

2004
Rohit Patil, *mc*
Sung Ho Park, *mc*
Xiaoyan Song, *mc*

2003
D. Collin Day, *mc*
Ellen Day, *mc*
Scot Fernandez, *mi*
Ed Hattenberger, *mc*
Steve Jacob, *mi*
Xiaoyun Jiang, *pi*
Garrett Johnson, *pi*
David Robinson, *mi*
Mitchell Rosen, *pi*
Deniz Schildkraut, *mc*
Qun Sun, *pi*

2002
Arturo Aguirre, *mc*
Jason Babcock, *mc*
Anthony Calabria, *mc*
Jen Cerniglia Stanek, *mi*
Scot Fernandez, *mc*
Shuxue Quan, *pi*
Yat-ming Wong, *mi*

2001
Jason Gibson, *mc*
Alexei Krasnoselsky, *mc*
Lawrence Taplin, *mc*
Sun Ju Park, *mc*
Michael Sanchez, *mi*
Barbara Ulreich, *mi*

2000
Sergio Gonzalez, *mc*
Sharron Henley, *mc*
Patrick Igoe, *mi*
Susan Lubecki, *mc*
Richard Suorsa, *mc*

1999
Gus Braun, *pi*
Barbara Grady, *mc*
Katherine Loj, *mc*
Jonathan Phillips, *mi*
Mark Reiman, *mc*
Mark Shaw, *mc*
Di-Yuan Tzeng, *pi*
Joan Zanghi, *mc*

1998
Scott Bennett, *mc*
Fritz Ebner, *pi*
Garrett Johnson, *mc*
Naoya Katoh, *mc*
David Wyble, *mc*

1997
Peter Burns, *pi*
Christopher Hauf, *mc*
Brian Hawkins, *mc*
Alex Vaysman, *mi*

1996
Karen Braun, *pi*
Cathy Daniels, *mc*
Yue Qiao, *mi*
Jack Rahill, *mi*
Hae Kyung Shin, *mi*

1995
Richard Alfvin, *mc*
Seth Ansell, *mc*
Sue Farnand, *mi*

1994
Audrey Lester, *mc*
Jason Peterson, *mi*
Debra Seitz Vent, *mi*
James Shyu, *mc*

1993
Nathan Moroney, *mc*
Elizabeth Pirrotta, *mc*
Mitchell Rosen, *mi*

1992
Mark Gorzynski, *mi*
Taek Kim, *mi*
Rich Riffel, *mi*
Brian Rose, *mc*

1991
Yan Liu, *mc*
Ricardo Motta, *mi*
Amy North, *mc*
Greg Snyder, *mi*
Michael Stokes, *mc*

1989
Mitch Miller, *mi*
Kelvin Peterson, *mi*
Lisa Reniff, *mc*

1987
Denis Daoust, *mi*
Wayne Farrell, *mi*

1986
Mark Fairchild, *mi*

Key:
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MCSL Advisory Board

The MCSL Advisory Board is an advisory group composed of industrial and academic experts in color science and color aesthetics. Their role is to insure that the activities of MCSL are in concert with industrial needs, to evaluate the degree programs in Color Science, to promote funding opportunities, and to provide employment opportunities to Color Science and Imaging Science graduates focused on color-related problems.

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Dr. David Alman, DuPont
Dr. Jack Hsia, NIST
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Mrs. Joy Turner Luke, Studio 231
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Mr. Milton Pearson
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