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Munsell Color Science Laboratory

Annual Report 2003

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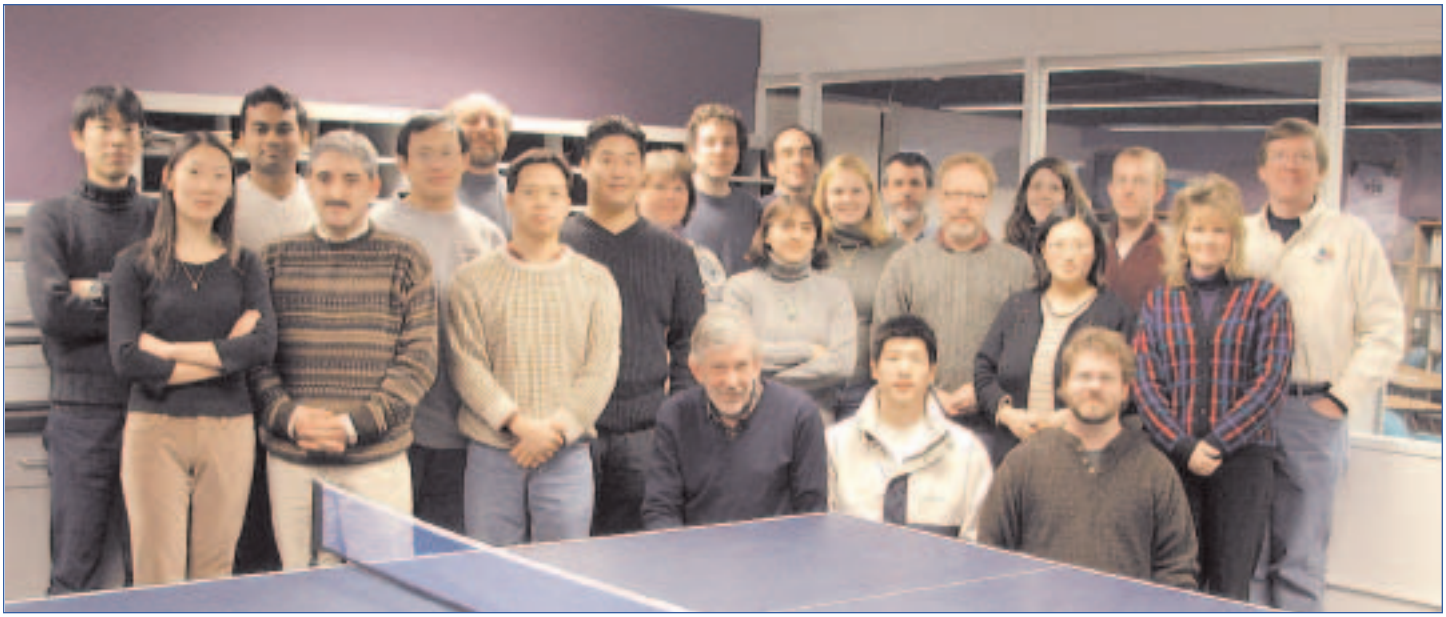


From The MCSL Family

Director's Welcome

Welcome to the 2003 version of the Munsell Color Science Laboratory Annual Report. This piece has become our periodic reality check and promotional piece for recruiting new students and research projects.

In last year's welcoming note I wrote, "we've never been known to sit still" in MCSL. Little did I know just how true that statement would become in 2003. As I write this in early 2004, we have just settled the lab into its new facilities in building 18 on the south side of RIT's campus. Formerly the Link Building, building 18 is now officially called the Color Science Building. (If you'd like to make a donation to have your name on our building, let me know and perhaps we can arrange something!). We are all very excited about the opportunities made possible by our new facilities and still busy completing the renovations. The 2004 report should be full of images of our new facilities in their full glory.

In 2003, we celebrated the 20th anniversary of MCSL's founding with an open house and reception during the IS&T PICS conference that was held in Rochester. We also celebrated by designing our new facilities including the Franc Grum Color Science Learning Center in honor of our first lab Director. Thanks to numerous donations from alumni and friends (acknowledged later in this report), we are constructing a wonderful color science teaching and learning facility for the benefit of all our future students.

MCSL personnel also made some significant moves in 2003. Francisco Imai moved to the less-cold climate of the silicon valley to gain some industrial experience at Pixim. Noboru Ohta is spending more time in Japan helping build our relationships there in his new position as Visiting Research Professor. Mitch Rosen has expanded his activities to include some research on eye-tracking in RIT's Visual Perception Laboratory and is also working on a new project in MCSL on museum imaging in collaboration with Prof. Franziska Frey of RIT's School of Print Media. We hope to continue to expand such collaborations to other areas.

2003 was a banner year for MCSL graduates. Four students completed their Ph.D. degrees: Qun "Sam" Sun, Xiaoyun "Willie" Jiang, Mitch Rosen, and Garrett Johnson. Sam and Willie have taken industrial positions at Ricoh Innovations and Qualcom respectively, while Mitch and Garrett remain at RIT. At the M.S. level Ellen Day, Collin Day, Ed Hattenberger, and Scot Fernandez all completed degrees and moved on to Pantone, HP-Boise (both Collin and Ed), and Hallmark respectively. Congratulations and best wishes to our graduates.

Our mission, objectives, research activities, and publications are described throughout this report. As I've pointed out annually, it's all about the students. I thank each and every one of them for making our day-to-day activities possible and most enjoyable. Without the students, we'd have no lab and without our research and educational sponsors, we'd have no students. Thanks again to all who have supported our activities through research funding, equipment donations, and gifts.

Mark D. Fairchild
Xerox Professor of Color Science
Director, Munsell Color Science Laboratory

Munsell Color Science Laboratory

The RIT Munsell Color Science Laboratory (MCSL) was established in 1983 after the the Munsell Color Foundation, Inc. transferred its assets to RIT to create an endowment. Franc Grum was the lab's first Director and the first R.S. Hunter Professor of Color Science, Appearance and Technology. Since then MCSL has 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.

The aims and purposes of the Munsell Foundation as stated in its bylaws were ... to further the scientific and practical advancement of color knowledge and, in particular, knowledge relating to standardization, nomenclature and specification of color, and to promote the practical application of these results to color problems arising in science, art, and industry.

Our Objectives

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.

Our Mission Is Education

MCSL educates graduate students and industry employees both nationally and internationally. MCSL has been providing high quality state-of-the-art education and research for over 20 years.

Master's and Ph.D. Degrees

MCSL offers the only Master's degree program in Color Science in the country and has over 50 alumni in the field world-wide. MCSL graduates are in high demand and have accepted industrial positions in electronic imaging, color instrumentation, colorant formulation and basic and applied research. MCSL students complete Master's and Ph.D. degrees through the programs within the Center for Imaging Science.

Summer School of Industrial Short Courses

Summer 2004 offers an all-new short course designed by the MCSL faculty to provide participants with a fundamental understanding of the principles of colorimetry and their application to the production, control, and reproduction of color. Called, Essentials of Color Science. It will take place June 8-10, 2004. See our detailed website, to learn more and register: <www.cis.rit.edu/mcsl>.

Visiting Scientist Program

For more than a decade MCSL has been hosting industrial visiting scientists. The scientists spend 1-2 years in residence at MCSL and work on fundamental research problems of interest to their company and MCSL researchers.

Collaborative Research

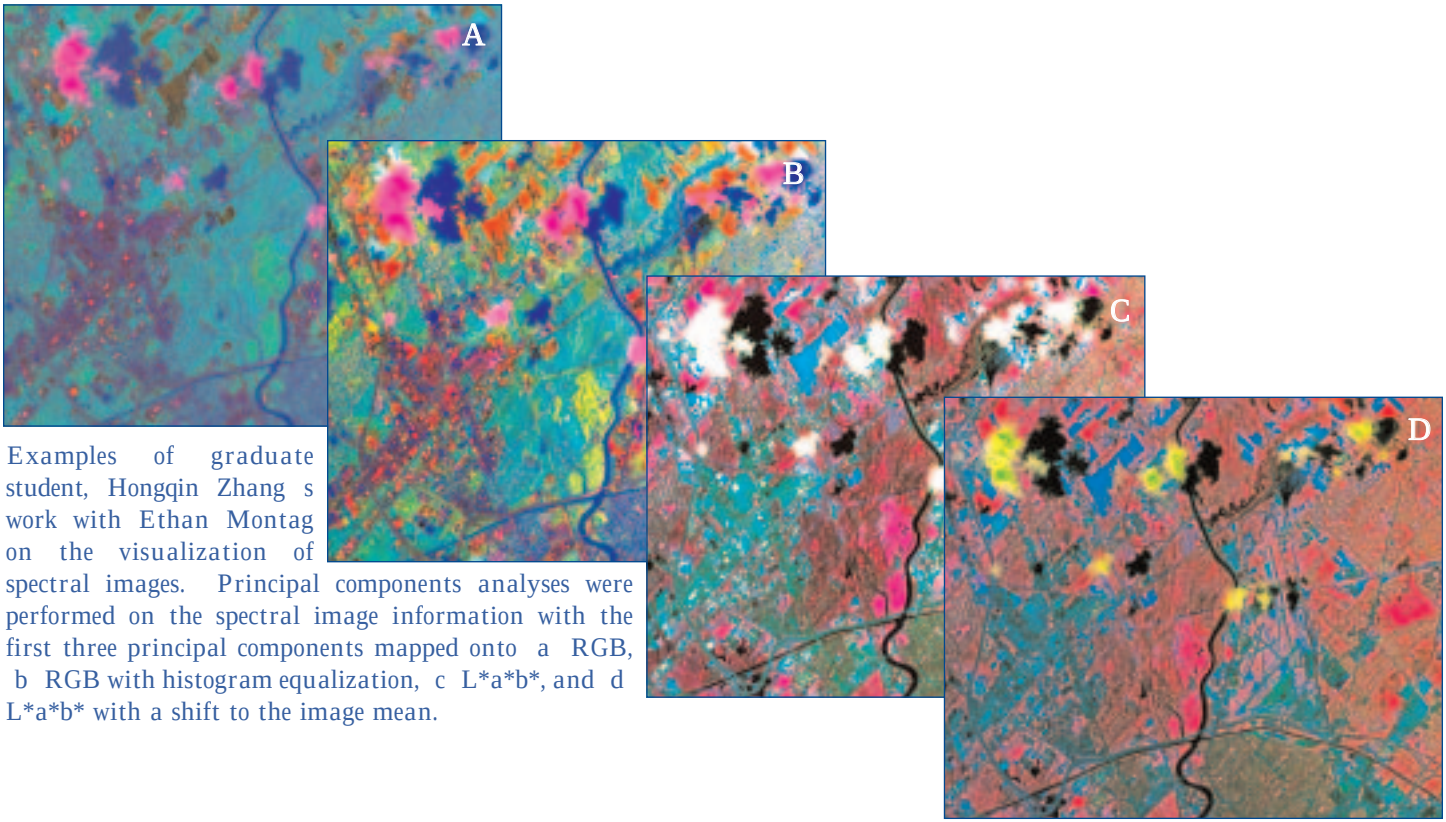
Fundamental to our educational mission is collaborative research with industry on important, relevant, and intriguing problems of color science and technology.

Color Measurement & Science

Color measurement is the foundation on which MCSL was built over 20 years ago. The lab continues to work in areas of basic color measurement to support our other research projects and in fundamental color science to satisfy intellectual curiosities in the field. One aspect of this is the publication of text and professional books. The second edition of Color Appearance Models was completed in 2003 and will be published in 2004.[23] Two of Noboru Ohta's books on color engineering and reproduction were published in translated versions.[45,46] A chapter on visual psychophysics and colorimetry was part of the Handbook of Digital Color Imaging.[32]

Much of our measurement work is prompted by the need to calibrate and characterization of imaging devices.[47] Additional work was published on the measurement and characterization of direct-view LCD monitors.[3,6] Takayuki Ogasahara, a visiting scientist, published work on the characterization of printers.[43,44] A color measurement job at MCSL gained some notoriety when the sponsor's analysis showed that certain types of LCD projectors are subject to significantly greater aging artifacts than comparable micro-mirror-based projectors. A side benefit of this measurement work use of the data to develop a characterization technique for micro-mirror projectors.[61]

Dave Wyble posing with his video projector color measurement setup. While it s a pretty picture, unfortunately he couldn t really measure them all at once and the actual test targets were less interesting visually.

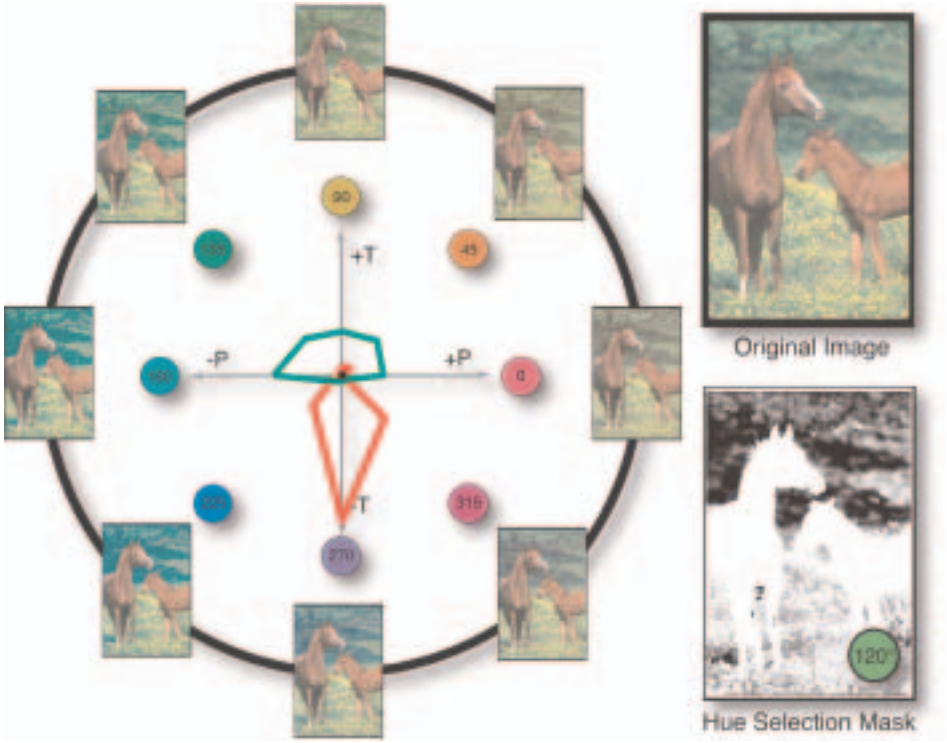


Examples of graduate student, Hongqin Zhang s work with Ethan Montag on the visualization of spectral images. Principal components analyses were performed on the spectral image information with the first three principal components mapped onto a RGB, b RGB with histogram equalization, c L*a*b*, and d L*a*b* with a shift to the image mean.

Fundamental color science research examined topics such as the nature of color matching functions,[38] the nature of color space,[42] the perception of brightness,[53] and the degree to which various hue shifts become objectionable in image reproduction.[59] In slightly more practical research, a summary paper on the combination of spatial filtering and CIE color difference equations was published,[36] as was an evaluation of the precision and accuracy of commercial spectrophotometers.[60]

Image Appearance & Modeling

Research on image appearance, quality, and modeling continued to be of significant interest to many in the lab. Garrett Johnson completed his Ph.D. dissertation[34] on the measurement and modeling of image differences and published several papers related to the topic .[24,33] This work, and several related projects, contributed to the ongoing development of an image appearance model, iCAM, that has been applied to color appearance, high-dynamic-range image and video rendering, and image quality/difference metrics.[18,20-22,35] Anthony Calabria's research on the perception and modeling of contrast in images was published in a two-part paper[8,9] and was also used to evaluate the iCAM framework.



Visualization of example results from a hue preference experiment by Lawrence Taplin and Garrett Johnson. The selected hue region green in this example was shifted in IPT space to produce manipulated images and observers evaluated their preference. The green line illustrates the degree of positive preference improvement in the image for each shift while the red line indicates the degree to which shifts in those directions were objectionable degradation of the image .

MCSL summer interns from local high schools collected high-dynamic-range images of various landmarks on the RIT campus here the RIT color cube in the Carlson building . The inset shows a linear rendering of the image. The main image is a locally-adapted rendering based on the iCAM algorithm.

Garrett demonstrates his new high-tech digital interface for print image quality experiments.

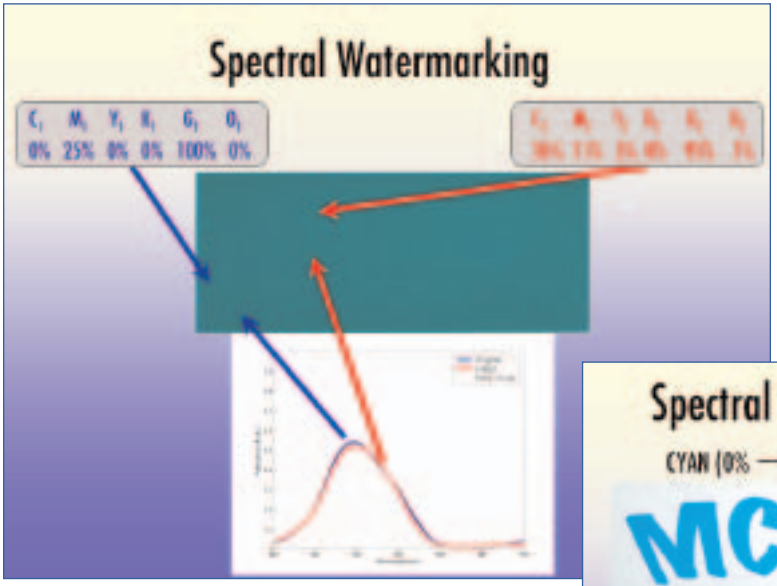
A variety of research projects were also carried out to examine fundamental properties of visual experimentation. Jason Babcock's work on eye-tracking during various forms of psychophysical tasks was published.[1,2] Ethan Montag presented some work on various techniques for performing color difference experiments[39,40] and a Monte Carlo simulation aimed at deriving models to create confidence intervals for interval scales derived from the paired-comparison experiments commonly used in the lab.[41] Qun Sun, as a part of his dissertation on spectral image capture, also published some work on the analysis and modeling of image quality in spectral imaging systems.[55,57,58] Some more recent work looked at the application of multidimensional techniques to determine the most important factors in visual assessment of image quality in electrophotographic prints.[37]

Spectral Color Reproduction

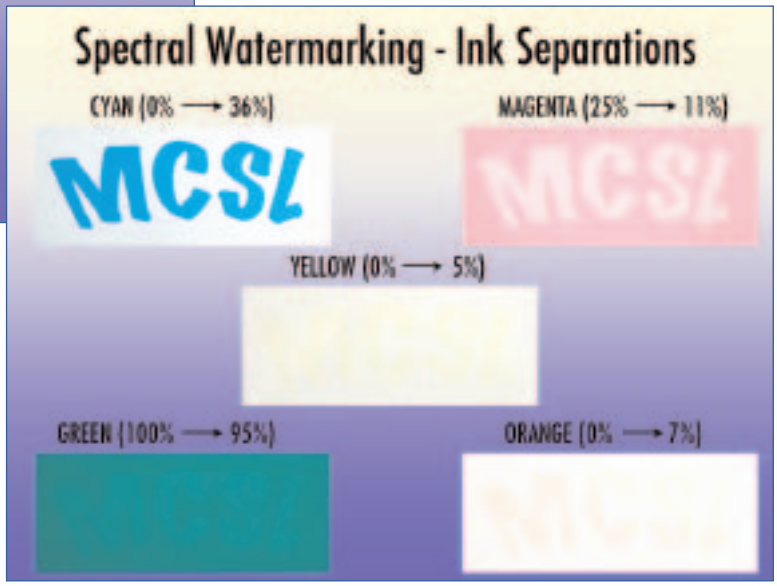
Image reproduction using spectral information beyond the normal three or four channels is an area of active research around the world. A team led by Francisco Imai put commercially-available pieces together to examine the feasibility of an end-to-end spectral reproduction system.[27] Mitch Rosen complete his Ph.D. dissertation[49] examining the roadblocks to spectral reproduction systems, dealing with many of them, and developing proposals for spectral color management systems.[51]

Xiaoyun Jiang completed her Ph.D. dissertation[31] on spectral and colorimetric illuminant estimation for camera systems,[30] an area of analysis related to the estimation of spectral reflectance distributions from limited numbers of color samples.[29] Qun Sun used similar techniques, and developed others, in his Ph.D. dissertation[54] on spectral imaging for human portraiture and spectral image quality.[56]

Yongda Chen and Ed Hattenberger discuss their poster presentations at the 11th CIC and PICS conferences. Back at MCSL, Yongda shows off his cactus pen, awarded for his runner-up finish in the balloting for best poster at the conference.



An example of applying spectral redundancy in multi-ink printing systems to create spectral watermarks. The MCSL letters and background have essentially identical spectral reflectance characteristics and therefore cannot be distinguished under any lighting. However examination of the separations e.g., by viewing the half-tone dot patterns will reveal the watermark.



Yongda Chen, in the early stages of his dissertation, published a paper on spectral color separation from CIELAB image data to CMYKGO ink amounts10 addressing an important practical problem in multi-ink printing systems. On the other end of the student career timeline, alumnus Shuxue Quan had more of his work on the modeling and optimization of camera spectral responsivities published in 2003.[48]

Ed Hattenberger completed an M.S. thesis[25] on the analysis of spectral redundancy (multiple ink combinations producing virtually identical spectral reflectances) in six-color inkjet printing systems that spawned several related papers on the topic and potential applications.[26,50,52]

Color Science for Cultural Heritage

It is very exciting and rewarding to see the results of MCSL research being readily applied to the conservation, reproduction, archiving, and study of our cultural heritage. Research on systems to make these applications more feasible continues to be a major focus of the lab. Ellen Day completed her M.S. thesis[14] on the psychophysical evaluation of various spectral imaging techniques when displayed images were compared directly with original objects and two papers were published on that research.[15,17] Collin Day (No relation to Ellen.) examined the selection of filters for spectral image capture based on commercial trichromatic cameras in his M.S. thesis.[11] Collin also published two technical reports on the evaluation of imaging systems for spectral image capture.[12,13]

Roy and Lawrence check out the accuracy of one of their spectral camera configurations in the new spectral imaging lab.

This research team will work on a 15-month project to benchmark and improve the quality of art imaging in American museums. Pictured from left: Roy Berns, Lawrence Taplin, Erin Murphy, Mitch Rosen and Franziska Frey.

Roy performs a little visual colorimetry matching Munsell chips to Seurat s painted points in order to accurately work on a digital restoration.

Some general studies on spectral imaging of artwork were also completed. These included a case study imaging Matisse's Pot of Geraniums,[6] the creation of color accurate archives,[7] and on-site imaging at the National Gallery of Art in Washington, DC.[28] Research work on the optical properties of varnishes also continued.[4,5]

During the summer a new research program aimed at benchmarking the quality of direct digital imaging of cultural heritage in America commenced. Supported by the Andrew W. Mellon Foundation, this program includes a survey, detailed case studies and developing a procedure to quantify color and image quality, using international standards to the greatest extent possible.

MCSL Students

Christine Bagwell, M.S., Color Science
Jennifer Cerniglia Stanek, M.S., Imaging Science
Yongda Chen, Ph.D., Imaging Science
Jim Hewitt, M.S., Imaging Science
Jiang Kuang, Ph.D., Imaging Science
Justin Laird, M.S., Color Science
Chengmeng Liu, Ph.D., Imaging Science
Mahnaz Mohammadi, Ph.D., Imaging Science
Erin Murphy, M.S., Color Science
Mahdi Nezamabadi, Ph.D., Imaging Science
Yoshio Okumura, M.S., Color Science
Sung Ho Park, M.S., Color Science
Rohit Patil, M.S., Color Science
Joe Slomka, M.S., Color Science
Xiaoyan Song, M.S., Color Science
Yat-ming Wong, M.S., Imaging Science
Hongqin Zhang, Ph.D., Imaging Science

Visiting Scientists

Takayuki Hasegawa, Toppan
Nobuhito Matsushiro, Oki Data
Takayuki Ogasahara, Canon
Hiroshi Yamaguchi, Fuji Photo

Alumni

2003
Ellen Day, M.S., Color Science
Collin Day, M.S., Color Science
Scot Fernandez, M.S., Imaging Science
Ed Hattenberger, M.S., Color Science
Steve Jacob, M.S., Imaging Science
Xiaoyun Jiang, Ph.D., Imaging science
Garrett Johnson, Ph.D., Imaging Science
David Robinson, M.S., Imaging Science
Mitchell Rosen, Ph.D., Imaging Science
Deniz Schildkraut, M.S., Color Science
Qun Sun, Ph.D., Imaging Science

2002
Arturo Aguirre, M.S., Color Science
Jason Babcock, M.S., Color Science
Anthony Calabria, M.S., Color Science
Scot Fernandez, M.S., Color Science
Shuxue Quan, Ph.D., Imaging Science

2001
Jason Gibson, M.S., Color Science
Alexei Krasnoselsky, M.S., Color Science
Lawrence Taplin, M.S., Color Science
Su Ju Park, M.S., Color Science
Michael Sanchez, M.S., Imaging Science
Barbara Ulreich, M.S. Imaging Science

2000
Sergio Gonzalez, M.S., Color Science
Sharron Henley, M.S., Color Science
Patrick Igoe, M.S., Imaging Science
Susan Lubecki, M.S., Color Science
Richard Suorsa, M.S., Color Science

1999
Gus Braun, Ph.D., Imaging Science
Barbara Grady, M.S., Color Science
Katherine Loj, M.S., Color Science
Jonathan Phillips, M.S., Imaging Science
Mark Reiman, M.S., Color Science
Mark Shaw, M.S., Color Science
Di-Yuan Tzeng, Ph.D., Imaging Science
Joan Zanghi, M.S., Color Science

1998
Scott Bennett, M.S., Color Science
Fritz Ebner, Ph.D., Imaging Science
Garrett Johnson, M.S., Color Science
Naoya Katoh, M.S., Color Science
Dave Wyble, M.S., Color Science

1997
Peter Burns, Ph.D., Imaging Science
Brian Hawkins, M.S., Color Science
Christopher Hauf, M.S., Color Science
Alex Vaysman, M.S., Imaging Science

1996
Karen Braun, Ph.D., Imaging Science
Cathy Daniels, M.S., Color Science
Yue Qiao, M.S., Imaging Science
Jack Rahill, M.S., Imaging Science
Hae Kyung Shin, M.S., Imaging Science

1995
Richard Alfvin, M.S., Color Science
Seth Ansell, M.S., Color Science
Sue Farnand, M.S., Imaging Science

1994
Audrey Lester, M.S., Color Science
Jason Peterson, M.S., Imaging Science
James Shyu, M.S., Color Science
Debra Seitz Vent, M.S., Imaging Science

1993
Nathan Moroney, M.S., Color Science
Elizabeth Pirrotta, M.S., Color Science
Mitchell Rosen, M.S., Imaging Science

1992
Mark Gorzynski, M.S., Imaging Science
Taek Kim, M.S., Imaging Science
Rich Riffel, M.S., Imaging Science
Brian Rose, M.S., Color Science
Michael Stokes, M.S., Color Science

1991
Yan Liu, M.S., Color Science
Ricardo Motta, M.S., Imaging Science
Amy North, M.S., Color Science
Greg Snyder, M.S., Imaging Science

1989
Mitch Miller, M.S., Imaging Science
Kelvin Peterson, M.S., Imaging Science
Lisa Reniff, M.S., Color Science

1987
Denis Daoust, M.S., Imaging Science
Wayne Farrell, M.S., Imaging Science

1986
Mark Fairchild, M.S., Imaging Science

2003 MCSL Publications

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References by Research Theme

(1) Image Appearance and Quality
1, 2, 8, 9, 18, 20-22, 24, 33-35, 37, 39-41, 55, 57, 58, 65

(2) Spectral Color Reproduction
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(3) Color Science for Cultural Heritage
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(4) Color Measurement and Science
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Franc Grum Color Science Learning Center

Created in celebration of the first 20 years of the RIT Munsell Color Science Laboratory.

In 1983, Franc Grum founded the Munsell Color Science Laboratory. Serving as the lab's first Director and the first R.S. Hunter Professor of Color Science, Appearance, and Technology, Franc was responsible for establishing facilities and initiating color science educational programs. Franc's untimely death in 1985 prevented him from witnessing the continuing results of his vision, determination, and effort that made world-class color science education and research at RIT a reality. As a lasting legacy to Franc's mission, this facility was created in dedication and celebration of his foresight, hard work, and standards of excellence through contributions from the following alumni and friends of the lab.

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