RICHARD S. HUNTER PROFESSORSHIP

MUNSELL COLOR SCIENCE LABORATORY

ANNUAL REPORT
1991

Rochester Institute of Technology

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Table of Contents

Program Objectives

The Richard S. Hunter Professorship in Color Science, Appearance, and Technology was established in 1983 by a gift from Richard and Elizabeth Hunter. They recognized a need for perpetual education and research in this critical area. The Munsell Color Science Laboratory was established in 1983 after the dissolution of the Munsell Color Foundation, Inc. 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."

Both endowed programs operate hand in hand on a daily basis. The following four basic objectives help guide their activities: 1) To provide under-graduate and graduate education in color science, 2) To carry on research and development in color and appearance, 3) To establish a sound standardization program in areas where standards are either void or difficult to obtain from other sources, and 4) To provide an essential ingredient for the success of the first three -- namely, liaison with industry.

The Year In Review

One of the cliches to appear in 1991 is "cultural diversity;" during the past year I experienced tremendous cultural diversity through my travels relating to color. During June, I went to Australia to attend the International Association of Color (AIC) interim conference on Light and Color held in Sidney followed by the International Commission on Illumination (CIE) 22nd Session held in Melbourne. I met many new faces from around the world, rekindled old relationships, and thoroughly enjoyed the color enthusiasts from the Australian Color Society. Many were artists and designers; I always find their views insightful and challenging, particularly since I presented a paper at the AIC conference about the influence of cognitive clues and instructions on color perception. Interestingly, the aesthetic constituency were more receptive to my ideas than the colorimetrists.

During December, I went to Japan for the first time along with other faculty and staff from RIT to take part in a meeting of the Center for Imaging Science Industrial Associates Program. I also made several site visits to Japanese companies. The experience was exhilarating. I found the Japanese social and work cultures very different from my previous experiences. In particular, the Deming team approach to research and development made quite an impression on me; I hope to apply my new-found, first-hand knowledge within MCSL.

Within the laboratory, there were many changes this year. Our first visiting scholar from Konica Corporation, Po-Chieh Hung, returned to Japan. Konica sent a second scholar, Toru Hoshino. He will continue researching color reproduction concentrating on gamut mapping and preferred color reproduction. Near the end of the year, a visiting scholar from Dupont joined us, Taek Kim. Taek returns to RIT having been a undergraduate and graduate student in imaging science. Taek will also perform research in color reproduction. Mark Gorzynski, an associate scientist with MCSL for the last two years, left RIT and joined Tektronix in Beaverton, Oregon. Mike Stokes, one of our color science graduates, assumed Mark's position. In addition, Mike will pursue a doctoral degree in imaging science on a part-time basis.

Another area of change was the establishment of several industry-sponsored scholarships. R.R. Donnelley & Sons, who supported Mike Stokes last year, renewed their support; Elizabeth Pirrotta will be the Donnelley Scholar. Elizabeth will be performing experiments to test current color appearance models. BASF Corporation, Carpet Fibers Division, established a scholarship in the area of color and texture analysis using image processing. Seth Ansell, as the BASF Scholar, will be continuing the pilot experiments on texture analysis I described in April 1990 at the Symposium on Color and Appearance Instrumentation (SCAI) in Cleveland, Ohio. Eastman Kodak established a scholarship in color appearance psychophysics for hybrid imaging. Kodak will be supporting Amy North throughout her doctoral studies. We are very excited since this scholarship is a multi-year commitment.

Instrument manufacturers and a variety of corporations continue to support our programs by generously donating hardware and unrestricted funds. We have two new supporters: Monsanto Chemical Company and Welch Allyn, Inc. It is exciting to be supported by such diverse companies. In addition to scholarship support, R.R. Donnelley & Sons is also supporting our research efforts by loaning a Pixar II image computer. This is our second Pixar system and will greatly enhance our ability to make color appearance measurements.

As I write this review, I realize that our most important accomplishment has not been documented, the development of a color science "family." The commitment of Mark, Lisa, Mike, Colleen, and our students and visiting scholars to our shared vision of becoming an international color science resource is difficult to express in words. I am so proud of everyone. Mark was made a chairman of a CIE technical committee. Lisa developed a 45/0 measurement assurance program. Mike had his master's research accepted for presentation at the upcoming Williamsburg conference. Colleen now directs our industrial short courses and has begun making spectrophotometric measurements. Daily I am amazed by the care and thoughtfulness of the staff and their commitment to excellence. During 1992 I hope to expand our "family" by interacting with the rest of the RIT color community. Color is exploding in graphic design, the School for the American Craftsman, printing, electronic photography, and animation. I plan to use the personal monetary support of Mrs. Elizabeth Hunter to support my efforts in this area.

In closing, the future, as my secretary Colleen would say, looks colorful, indeed!

Roy S. Berns, Ph.D.
Richard S. Hunter Professor
Director, Munsell Color Science Laboratory

January, 1992

Faculty and Staff Activities

The following reports summarize the activities during 1991 of faculty, staff, and visiting scholars.

Mark D. Fairchild, Assistant Professor, (716) 475-2784
B.S., Imaging Science, Rochester Institute of Technology, 1986.
M.S., Imaging Science, Rochester Institute of Technology, 1986.
M.A., Visual Science, University of Rochester, 1989.
Ph.D., Visual Science, University of Rochester, 1990.

Could it be that my life is settling down? This is the first year that I can honestly say I did pretty much the same things as I did the year before ... how boring. Not really, there's no time for boredom at MCSL. It's tempting to use this section to write about research, papers, courses, technical committees, etc. But that information is elsewhere in this report. Instead, I'm using this space to try to share how my thinking about color science has developed over the past year.

My overall objective has been to better understand why colored stimuli appear the way they do. During the past 12 months, I've had 3 major influences: computers, photography, and psychology. I've been using and programming new computers with color imaging capability. The surprising thing about this is that these capabilities are quickly becoming part of general purpose computers such as NeXT and Macintosh workstations. Specialized hardware is no longer required. The capabilities of these machines make possible color appearance research that we couldn't have imagined just a few years ago. I've also been interpreting gallery shows at the International Museum of Photography. Training for this volunteer work and teaching a color reproduction course last spring have rekindled my enthusiasm for photography. Thinking about the history, aesthetics, and technology of photography has reminded me of many factors that influence the color appearance of objects and reproductions. It is no wonder so many significant contributions to color science were made by photographic researchers. Lastly, much of my research has pointed to factors beyond the physical that influence the appearance of colors. These cognitive factors are very important in color appearance and reproduction and I've been trying to learn more about them. I think these influences have given me a better understanding of why colors appear the way they do. I hope I'll be able to share.

Some of that sharing should take place through two new responsibilities I assumed this past year. I am co-chair of ISCC Interest Group #2, *Appearance, Vision, and Modeling* and chair of CIE TC1-34, *Testing Color Appearance Moaels.* I hope I can fulfill these duties to everyone's satisfaction.

Thanks to all involved with MCSL: students, staff, faculty, advisors, and supporters.

Lisa Reniff, Associate Scientist, (716) 475-7188
B.S., Chemistry, Rochester Institute of Technology, 1986.
M.S., Color Science, Rochester Institute of Technology, 1989.

It's hard to believe I've been working in the Laboratory for three years now. I can now say with experience that I enjoy my job very much. This position allows me to continue to learn deeper aspects of color science and areas of many other fields. The academic setting is very conducive to this with more courses and seminars than time allows. The seminar class that Roy and Mark lead every year is one that is fun with a different subject discussed every week based on recent journal articles. The various research projects continue to be interesting and expand my knowledge. Recently, I performed a project on the time course of adaptation, which required my introduction into the land of UNIX and C.

Another large component of this position that I find enjoyable is the opportunity to help people. A large portion of my day is spent helping students either with research ideas, how to work equipment or helping TA's set up laboratories. I also provide a service of measurement or characterization of materials for calibration for industrial use. However, interpreting the vocabulary of industry people to answer their questions is always challenging.

Having Mike join our staff in June was great. His enthusiasm and helpfulness are wonderful and infectious.

Mike Stokes, Associate Scientist, (716) 475-7186
B.S., Mathematics, University of Texas at Austin, 1989.
M.S., Color Science, Rochester Institute of Technology, 1991.

I joined the Munsell Lab in June after spending the last two years here as a graduate student. Before coming to RIT I had spent fifteen years in the slide reproduction and video transfer industries. My industry training is in research, quality control, computer programming and production management. I have also been accepted into RIT's Ph.D. program in Imaging Science and am working part-time toward this degree.

My first six months on staff here have been very busy. I officially received my Master's degree in August and submitted my first article for publication in September. A second article has been accepted for presentation and publication at the Williamsburg Conference on Cross-Media Color Reproduction in 1992. Both of these articles relate to my research on colorimetric tolerances for digital images.

The laboratory has continued to grow and I have been busy trying to install and maintain the computer systems. The student color modeling lab has been converted to a Macintosh based system making it much easier for the students to work with. A second Macintosh based prepress system for research in color appearance and reproduction is currently being installed in a room with controlled illumination. A mobile IBM-PC based system for doing color measurements around the lab was created, after receiving a second Photo-Research Spectroradiometer. R. R. Donnelley generously donated a second Pixar Imaging Computer which was promptly installed on our second Sun computer system.

I am finding it exciting to work with the students, forcing me to shore up my knowledge of color science.

Toru Hoshino, Visiting Scholar
B.S., Imaging Science and Engineering, Chiba University, 1986.
Working for Konica Corporation from 1986 to present

Time goes too fast. I have already spent nine months here since February when I came here as the second visiting scholar from Konica. Being in a new country and living by myself, I felt that there were lots of hard things to do: cooking, washing dishes, laundry, and so on. Would I be doing these same things if still in Japan? Maybe. Anyway, I think I should have found a wife and come here with her.

This year has been in preparation for my research. Besides English language and C language, I learned lots of new things in color science in this laboratory. I now have many ideas about color manipulation using a recent color appearance model which will be my major concentration as my research project.

I would like to try to get good results in my research project and improve myself with the good facilities and people in this laboratory during the next fifteen months.

Taek Gyu Kim, Visiting Scholar
B.S. Imaging and Photographic Technology, RIT, 1987.
M.S. Imaging Science, RIT.
Working for DuPont from 1989 to present.

Moving back to Rochester was quite a challenge after being spoiled by the California weather. But thinking back about my previous time at RIT where my "office" was a converted photographic darkroom, it is really exciting to have a room with a view in the Center for Imaging Science. I am still trying to get used to the new environment. I am gearing up. I am ready to explore fundamentals of the color world.

My current interest is in the calibration of devices for independent color space including color imaging processing using new appearance models. I am learning more about color instruments with a different view point, too. Getting answers from people at Munsell Color Science Laboratory for all kinds of trivial questions that I had while working in the industry is really helpful. I found the questions were not trivial after all.

I will go back to DuPont Imaging System at the end of 1992. The kind of relationship I have found with the Munsell Color Science Laboratory I will keep with me as my contribution to DuPont grows.

Students

The following are students studying in color science.

FULL TIME GRADUATE

Seth Ansell, M.S. Candidate, Color Science
B.S., Imaging Science, Rochester Institute of Technology, 1989.

Gaurav Govil, M.S. Candidate, Computer Science
B.S., Computer Science, Rochester Institute of Technology, 1989.

Timothy Kohler, M.S. Candidate, Color Science
B.S., Printing Technology, Western Washington University, 1991.

Nathan Moroney, M.S. Candidate, Color Science
B.S., Color Science, Philadelphia College of Textiles and Science, 1991.

Amy North, Ph.D. Candidate, Imaging Science
B.S., Imaging Science, Rochester Institute of Technology, 1988.
M.S., Color Science, Rochester Institute of Technology, 1991.

Elizabeth Pirrotta, M.S. Candidate, Color Science
B.S., Color Science, Philadelphia College of Textiles and Science, 1990.

Brian Rose, M.S. Candidate, Color Science
B.S., Color Science, Philadelphia College of Textiles and Science, 1990.

PART-TIME GRADUATE

Jim Adams, Ph.D. Candidate, Imaging Science
B.S., Physics, Monmouth College, 1979.
B.S., Electronic Device Physics, Monmouth College, 1979.
M.S., Optics, University of Rochester, 1984.

Richard Riffel, M.S. Candidate, Imaging Science
A.S., Imaging Science, Rochester Institute of Technology, 1985.

Mike Stokes, Ph.D. Candidate, Imaging Science
B.S., Mathematics, University of Texas at Austin, 1989.
M.S., Color Science, Rochester Institute of Technology, 1991.

Debbie Vent, M.S. Candidate, Imaging Science
B.S., Optics, University of Rochester, 1988.

Jeffrey Wang, Ph.D. Candidate, Imaging Science
B.S., Graphic Arts, Chinese Culture University, 1982.
M.S., Imaging Science, Rochester Institute of Technology, 1988.

FULL-TIME UNDERGRADUATE

Paul Doll, B.S. Candidate, Imaging Science

Alex Granica, B.S. Candidate, Imaging Science

Rebecca Ouellette, B.S. Candidate, Imaging Science

Adam Portnoy, B.S. Candidate, Imaging Science

Funding

The Richard S. Hunter Professorship and Munsell Color Science Laboratory has been generously supported by industrial and individual donors. Many of our research efforts, the maintenance of our facilities, and the support of students would not be possible without this support. The support from instrument manufacturers continues to flourish. Having state-of-the-art instrumentation makes our industrial seminars and our academic coursework much more relevant.

The following lists our supporters during the time period of this annual report.

SCHOLARSHIPS

Scholarship support is difficult to quantify. Corporations may contribute direct and future funding, technical support, hardware, and Summer intern positions. The total costs for a full-time student including course work, 12 month stipend, and laboratory support are approximately $40,000 per calendar year. The following scholarships were established during 1991:

BASF Corporation

Eastman Kodak Company

R.R. Donnelley & Sons, Incorported

UNRESTRICTED RESEARCH GRANTS AND GIFTS

3M Company.....$5,000

Elizabeth Hunter.....$10,000

Monsanto Chemical Company.....$10,000

PPG Industry Foundation.....$5000

Tektronix Incorporated.....$10,000

Welch Allyn, Incorporated.....$5,000

DEVICES

Donor	*Device*	*Value*
BYK Gardner, Incorported	BYK Color Sphere	$12,000
Datacolor International	Tape Series	$350
	Paint II software upgrade	$2,000
Hewlett Packard Laboratory	Graphic Accelerator	$17,000
Hunter Associates Laboratory	Portable Spectrophotometer w/utilities	$10,000
LMT	The Photonic Directory	$80
Macbeth/Munsell Color Co.	Munsell Color Samples	$350
Minolta Corporation	CM-1000 Spectrophotometer	$19,500
	CA-100 Color Analyzer	$5,880
	Data Processor DP 101	$1,460
	CM 2002 Spectrophotometer	$11,500
Photo Research	PR703A Spectroradiometer	$20,000
R.R. Donnelley & Sons, Inc.	Pixar II - Long Term Loan	$70,000
Tektronix, Incorporated	TekColor System Implementor's Guide	$250
	TekColor software	$50
Welch Allyn, Incorporated	Opthalmoscope	$200

Research Contracts:

DuPont Company
Topic: Industrial color tolerances

Xerox Corporation
Topic: Measurement assurance program for 45/0 spectrophotometry

Research topics that were investigated in the past year are listed below in no particular order. The sources of funding are listed in brackets. The acronym MCSL means that the research was supported with the general research funds of the Munsell Color Science Laboratory. The acronym RSHP means that the research was supported through the Richard S. Hunter Professorship. We have provided a brief description on what each topic is about and this year's progress. Please refer to the publications list on pages 18 and 30 for references to more information on this research and feel free to contact any of us at the laboratory.

Chromatic Adaptation and Color Appearance Modeling
[MCSL, Du Pont Imaging]
Mark Fairchild

A chromatic adaptation model was reported at the 22nd CIE session and appeared in *Color Research and Application* in 1991. This model and other color appearance models have been implemented for use in color reproduction research. Preliminary experiments have shown this model to perform very well for cross-media color reproduction. Much of this work will be discussed at the upcoming ISCC/TAGA Williamsburg meeting in 1992.

Measurement Assurance Programs for Spectrophotometry
[Xerox Corporation, MCSL]
Lisa Reniff, Mark Fairchild, Roy Berns

A measurement assurance program (MAP) was developed for 45/0 spectrophotometry. Research on a d/0 program is ongoing. These programs allow subscribers to measure a small set of tiles and then return the data to MCSL for evaluation. The subscribers then receive a report indicating the accuracy of their instrument and possible systematic errors it might be suffering from. The 45/0 MAP has been carried out with several sites.

Helmholtz-Kohlrausch Effect Modeling
[MCSL]
Mark Fairchild, Elizabeth Pirrotta

Given high and low chroma object colors of equal luminance factor, the high chroma color will appear lighter. This phenomenon is sometimes referred to as the Helmholtz-Kohlrausch effect. A model has been developed to correct the CIE L* equation so that it can predict the perceived lightness of chromatic as well as achromatic object colors. This model was reported at the 1991 ISCC meeting and has

appeared in the December *Color Research and Application*. Additional data have been obtained from CIE TC1-21 for further testing of this model.

Exemplifying Photographic-Observer Metamerism
[MCSL, RSHP]
Roy Berns, Brian Rose

One of the difficulties in demonstrating metamerism in an article is including real examples. In this project, three color charts were prepared, one of textiles, one dyed paper, and one using artists' acrylic paints. The charts were reproduced using a photographic transparency system, a negative-positive system, and a four-color proofing system. Slides were produced that demonstrate the effects of photographic-observer metamerism. A tutorial article that includes these images is being prepared and a talk was presented at the 1991 ISCC annual meeting.

Evaluation of Object Texture Using Colorimetry-Based Image Processing
[BASF, MCSL]
Seth Ansell, Roy Berns

The aim of this project is to find a color space that can be used for representing images in which it is possible to separate the visual aspects of color and texture. These analyses will aid in the formulation of textured materials and the simulation of images of these materials. For example, an image of a blue piece of carpet could be changed to an image of a red piece of carpet without destroying the information that allows an observer to recognize it as carpet. This will serve as the M.S. thesis topic for Seth Ansell.

Testing Chromatic Adaptation Transforms
[R.R. Donnelley & Sons Company, MCSL]
Elizabeth Pirrotta, Mark Fairchild, Roy Berns

Prediction of the effects of chromatic adaptation is critical in many areas of color science. This project, Elizabeth's M.S. thesis, will mathematically compare the predictions of various chromatic adaptation models for a limited set of object colors and a range of viewing conditions. Then a pair of viewing conditions will be chosen for which the models make the most different predictions. A paired-comparison visual experiment will be carried out under these conditions to derive an interval scale that quantifies the quality of the models. This work should be completed in 1992.

Colorimetric Calibration of a Digital Film Recorder
[MCSL]
Mike Stokes, Roy Berns

Accurate color reproduction requires detailed knowledge of the characteristics of imaging devices. The objective of this project is to use physical and statistical models of photographic film to relate the tristimulus values of transparencies to the digital values sent to a film recorder. This work has already resulted in the ability to produce slides from computer images with significantly better tone and color reproduction than is typically available from standard digital film recorders.

Color Appearance of Images Presented in Different Media
[Eastman Kodak Company, MCSL]
Amy North, Mark Fairchild

Amy North is now in the Imaging Science Ph.D. program and will be investigating the appearance of color images in different media and viewing conditions. This research will be directly applicable to the work of CIE TC 1-27. The objectives are to test various color appearance models for predicting matches between various imaging modalities. Currently, a room is being designed and constructed with specialized lighting specifically for this type of research. Also a new Macintosh-based hybrid imaging system is being constructed that will be capable of scanning, displaying, and printing full-color images.

Color Science Education through Interactive Computer Graphics
[MCSL]
Brian Rose, Mark Fairchild

Graphics-based computer systems have provided new tools for scientists and designers that allow the manipulation of color in ways that are unfamiliar to many. Education in the fundamentals of color science, perception, and design would be very beneficial to these users. Brian Rose, for his M.S. thesis, is creating an interactive computer graphics program for the Macintosh that will be used by anyone with access to a color Macintosh and an interest in color to explore fundamental concepts of color science.

Color Tolerances of Pictorial Images
[R.R. Donnelley & Sons Company, Hewlett Packard, MCSL]
Mike Stokes, Mark Fairchild, Roy Berns

A large amount of data exists on the perceptual tolerances of individual colors. However, in color reproduction all of the colors in an image are changed simultaneously. This project examines just how far entire images can be

manipulated along perceptual dimensions of lightness, hue, and chroma before they become perceptually different and also until they become unacceptable. The results provide useful measurements of how close images have to be colorimetrically to be indistinguishable. The results will be presented at the upcoming ISCC/TAGA Williamsburg meeting in 1992.

Colorimetric Evaluation of Color Quantization in Digital Image Displays
[MCSL]
Alex Granica, Mark Fairchild

This is a senior research project designed to investigate the effects of quantization on color images. The result will be distributions of CIELAB color differences between nearest neighbor colors when images are quantized using 4, 6, 8, 10, and 12 bits per RGB channel and displayed on a typical graphics display monitor.

CIE-to-Munsell Conversion using Neural Network Models
[MCSL]
Paul Doll, Mark Fairchild

Neural networks, due to there huge number of free parameters, inherently nonlinear nature, and ease of implementation are finding many application in the realm of color science. This is a senior research project in which neural network models will be evaluated for performing CIE tristimulus value to Munsell notation transformations.

Color Difference Modeling
[Du Pont Automotive Products Department]
Roy Berns

The RIT-Dupont data base is comprised of 312 color difference pairs, each of equal visual difference. Equations are being derived from CIELAB and primary fundamentals (Stiles-Estevez-Hunt-Pointer) that model the data. The data base will also be used to test the performance of CMC and BFD. At the current stages of analysis, linear weightings of the chroma of the standard reduce the CIELAB variance as much as either CMC or BFD. Final equations will be tested by CIE TC 1-29 on industrial color difference evaluation.

Imaging Device Colorimetric Characterization Software
[Konica Corp., MCSL]
Po-Chieh Hung

Software has been developed that can be used to characterize color imaging devices using multidimensional look-up tables and interpolation. This software will allow the characterization of devices such as image scanners. The software allows the RGB signals from a scanner to be transformed to CIE tristimulus values given a look-up table that has been constructed with known samples of the same material. An article describing this research is in preparation.

Visual Determination of Constant Hue Loci
[Konica Corp., MCSL]
Po-Chieh Hung, Roy Berns

A visual experiment was performed using a CRT graphics display to determine loci of constant perceived hue for a wide variety of colors. The data are currently being analyzed in the CIELAB and CIELUV color spaces in order to determine which space might be better utilized for color gamut mapping when it is desired to keep hue constant. These data might also serve as valuable test data for color appearance models. An article describing this research is in preparation.

Investigation of Observer Metamerism
[Kollmorgen Foundation, New York State Center for Advanced Technology in Optics, MCSL]
Amy North, Mark Fairchild

This project was designed to measure inter- and intra-observer variation in the measurement of color matching functions and served as Amy North's M.S. Thesis. Measurements of color matching functions were made for a large number of observers utilizing an abridged method reported previously. In addition, the measurements were compared with similar ones that were made using the National Research Council (NRC) trichromator in Ottawa, Canada. An article on the techniques has been submitted to *Color Research and Application* and a second that evaluates the CIE method for predicting observer metamerism will be submitted soon.

Modeling the Spectral Reflectance of Ink-Jet Printer Output
[Hewlett Packard Co.]
Ken Parton, Roy Berns

This study, which served as Ken Parton's M.S. thesis, evaluated the applicability of single-constant K-M theory to predicting the spectral reflectance

factor of printed ink jet samples. Several important results were found for the particular system studied. First, the choice of surface correction parameter was critical in determining model effectiveness. Second, because of fluorescent quenching and the manner that ink-jet drops mix on paper, the usual Duncan mixing equations were only approximate. As a consequence, for high accuracy modeling, more complicated mixing equations should be developed. However for many product development needs, this approach will be adequate. These results were presented at the Non-Impact Printing Conference during October in Oregon.

Lightfastness of Color Hard Copy
[MCSL, Image Permanence Institute]
Rebecca Ouellette, Roy Berns

The technology available to create a color reproduction by other than convential silver halide has expanded greatly in the past few years. Images created with these devices are used for information and artistic purposes. It is not well documented whether these images have sufficient lightfastness. This senior project will investigate the light fading properties of several technologies including ink jet, dye diffusion, and electrophotography in comparison to conventional silver halide systems.

Characterization of a Flatbed Scanner
[MCSL]
Adam Portnoy, Mike Stokes

With the explosion of color desktop publishing in the last few years, the need for simple characterization methods for color desktop devices has become critical. Such characterizations include spatial non-uniformities, tone reproduction, and colorimetric reproduction. This senior project will characterize a typical flatbed scanner and test simple methods to calibrate these properties.

Gamut Mapping
[MCSL, Konica]
Toru Hoshino, Rab Govil, Roy Berns, Mark Fairchild

There are many issues that must be resolved in order to provide transparent cross-media reproduction to users. One of these issues is the disposition of colors that can be produced in one medium but are not producible in a second medium. Some of the colors produced in one medium might not be within the gamut of a second medium. When this occurs, an algorithm to move the out-of-gamut colors into the gamut of the printer must be implemented. Rab Govil will be implementing various algorithms to perform gamut mapping for his M.S. thesis in computer science. Toru Hoshino will be studying the theory of these techniques while visiting MCSL from Konica.

1991 Publications

The following is a list of reviewed articles and paper or abstract proceedings published or accepted for publication by faculty, staff, visiting scholars, and students of the Munsell Color Science Laboratory (listed in bold) during 1991. Past publications are listed beginning on page 27.

M.D. Fairchild, "Formulation and Testing of an Incomplete-Chromatic-Adaptation Model," *Color Res. Appl.* **16**, 243-250 (1991).

M.D. Fairchild and **E. Pirrotta**, "Predicting the Lightness of Chromatic Object Colors Using CIELAB," *Color Res. Appl.* **16**, 385-393 (1991).

L. Reniff, "1990 Annual Meeting of the Council for Optical Radiation Measurements," *Color Res. Appl.* **16**, 64-65 (1991).

M.D. Fairchild and **L. Reniff**, "Propagation of Random Errors in Spectrophotometric Colorimetry," *Color Res. Appl.* **16**, 360-367 (1991).

Y. Liu, R.S. Berns, and Y. Shu, "An Optimization Algorithm for Designing Colored Glass Filters to Simulate CIE Illuminant D65," *Color Res. Appl.* **16**, 89-96 (1991).

R.S. Berns, "Color Tolerance Feasibility Study Comparing CRT-Generated Stimuli with an Acrylic-Lacquer Coating," *Color Res. Appl.* **16**, 232-242 (1991).

R.S. Berns, D. Alman, **L. Reniff, G. Snyder**, and **M. Balonon-Rosen**, "Visual Determination of Suprathreshold Color-Difference Tolerances Using Probit Analysis," *Color Res. Appl.* **16**, 297-316 (1991).

K.H. Parton and **R.S. Berns**, "Color modeling of Ink-jet Ink on Paper using Kubelka-Munk Theory," *Proceedings of IS&T 7th International Congress on Advanced Non-Impact Printing Technologies*, Vol 2 (1991).

P.C. Hung, "Colorimetric Calibration for Scanners and Media," *Proceedings of the SPIE Vol. 1448, Camera and Input Scanner Systems*, 164-174 (1991).

Y. Liu, "Spectral Reflectance Modification of Neugebauer Equations," *Proceedings of the Technical Association of the Graphic Arts (TAGA)*, 154-171(1991).

R.S. Berns, "Color Science Education in the 1990's," *Proceedings of the Interim Conference of the International Color Association*, in press (1991).

R.S. Berns and **M.E. Gorzynski**, "Simulating surface colors on CRT displays: the importance of cognitive clues," *Proceedings of the Interim Conference of the International Color Association*, in press (1991).

R.S. Berns, "Visual determination of color-difference vectors using probit analysis: phase II," *Proceedings of the 22nd Session of the CIE,* part I, 35-38 (1991).

R.S. Berns and **M.E. Gorzynski,** "Characterizing the total uncertainty of the colorimetric calibration of color video displays," *Proceedings of the 22nd Session of the CIE,* part I, 35-38 (1991).

M.D. Fairchild, "A Model of Chromatic Adaptation," *Proceedings of the 22nd Session of the CIE,* part I, 33-34 (1991).

1991 Presentations

R.S. Berns, "Color Science: A blend of Physics and Perception," Sigma Pi Sigma RIT Chapter Honors Banquet, Rochester, NY, April.

M.D. Fairchild, "Predicting the Lightness of Chromatic Object Colors using CIELAB," Inter-Society Color Council Annual Meeting, New York, NY, May.

R.S. Berns and **B.J. Rose**, "Color Reproduction: Good News and Bad News," Inter-Society Color Council Annual Meeting, New York, NY, May.

M. Stokes, "Colorimetric Tolerances of Digital Images," Inter-Society Color Council Annual Meeting, New York, NY, May.

R.S. Berns and **M.E. Gorzynski**, "Simulating Surface Colors on CRT Displays: The Importance of Cognitive Clues," contributed paper, AIC Interim Meeting: Color and Light, Sydney, Australia, June.

R.S. Berns, "Color Science Education in the 1990's," keynote invited paper, AIC Interim Meeting: Color and Light, Sydney, Australia, June.

R.S. Berns, "Master of Science Degree Program in Color Science at Rochester Institute of Technology," presented to The Colour Society of Australia, Inc., Melbourne, Australia, July.

R.S. Berns, "Visual Determination of Color-Difference Vectors Using Probit Analysis: Phase II," presented poster paper, 22nd Session CIE Quadrennium, Melbourne, Australia, July.

R.S. Berns and **M.E. Gorzynski**, "Characterizing the Total Uncertainty of the Colorimetric Calibration of Color Video Displays," poster paper and invited paper for CRT workshop, 22nd Session CIE Quadrennium, Melbourne, Australia, July.

M.D. Fairchild, "A Model of Incomplete Chromatic Adaptation," CIE 22nd Session, Melbourne, July.

M.D. Fairchild, "Electronic Color Image Reproduction," Optical Society of America Annual Meeting, San Jose, CA, November.

Munsell Color Science Advisory Board

The Munsell Color Science Laboratory 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 the Munsell Color Science Laboratory are in concert with industrial needs, to evaluate the degree program 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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Color Science Courses

There were no major revisions in the color science curriculum during the past year. However, considerable enhancements in the teaching facilities have been made. Two teaching laboratories have been constructed within the Munsell Laboratory. The first is a spectroradiometry laboratory that contains an optical bench and two array radiometers. This lab is heavily utilized in the Applied Colorimetry, Theory of Color Measurement and Optical Radiation Measurements courses. Students make various measurements of the characteristics of light sources and the instruments and construct various devices such as tristimulus colorimeters and spectrophotometers. The color modeling lab is the second addition. This laboratory houses a hybrid imaging system that consists of a monochrome CCD video camera, a frame grabber, a digital image processor, a full-color CRT display, and a dye-diffusion video printer. Various filters can be placed in front of the camera to allow capture of RGB, CIE tristimulus, or spectral images. The images can then be manipulated and displayed through the image processor and hard-copy generated with the thermal printer. This system will allow students to study the colorimetric problems in all aspects of image capture, display, and reproduction and will be mainly used for the Color Modeling course. The need to teach the fundamental aspects of color digital imaging has also been recognized and these topics will be addressed in the Color Modeling course. The Color Science Seminar has proven to be a great success, giving students valuable experience in oral communication and critical literature review. A list of the current catalog descriptions of the required courses for the M.S. in Color Science follows.

PIMC-700 **4 Credit Hours** **VISION AND PSYCHOPHYSICS**

Registration#0926-700

This course provides an overview of the human visual system and psychophysical techniques used to investigate it. Topics include: the optical design of the eye; mechanisms of photoreception; neural coding; processing of visual information; and experimental techniques. Emphasis is placed on the mechanisms of color vision.

PIMC-701 **4 Credit Hours** **APPLIED COLORIMETRY**

Registration#0926-701

An introduction to the measurement and specification of color. The CIE system of colorimetry is presented with an emphasis on its practical application to common problems in quality control, reproduction, imaging, and formulation. The laboratory stresses the instrumental measurement of color and appearance.

PIMC-702 4 Credit Hours THEORY OF COLOR MEASUREMENT

Registration#0926-702

This course is designed for students with an understanding of the applications of colorimetry and presents the fundamental research leading to modern color measurement techniques. Material is presented to provide the background for further studies and research and development in the field of color science. Topics include; daylight specification, instrumental geometries, color matching functions, color appearance, color difference, and metamerism.

PIMC-801 3 Credit Hours COLOR SCIENCE SEMINAR

Registration#0926-801

A seminar course in which the students will study the literature in particular areas of color science and present that material to the class. Topics will be chosen based on student interest and current issues in the field.

PIMC-802 4 Credit Hours OPTICAL RADIATION MEASUREMENTS

Registration#0926-802

An in-depth treatment of the instrumentation and standardization required for accurate and precise measurements of optical radiation. The optical properties of objects and radiation sources will be covered. The optical and electronic design of spectroradiometric and spectrophotometric instrumentation is discussed in detail. The use of standard reference materials for the calibration and evaluation of instrumentation is explored. The laboratory is heavily stressed with students fully analyzing the design and performance of various instruments.

PIMC-803 4 Credit Hours COLOR MODELING

Registration#0926-803

This course explores mathematical techniques for predicting the coloring of various imaging systems including self-luminous displays, reversal color films, thermal dye transfer printers, and color scanners. Emphasis is placed on both analytical-physical and empirical-phenomelogical approaches. Models include Kubelka-Munk turbid media theory for opaque, transparent, and translucent systems; Grassmann's laws for additive systems; and linear and higher order masking equations. Statistical techniques include multiple-linear regression and non-linear optimization via the simplex method. Accompanying laboratory stresses the characterization, calibration, and prediction of various imaging devices in a systems approach.

PIMC-890 9 Credit Hours RESEARCH AND THESIS

Registration#0926-890

Thesis based on experimental evidence obtained by the candidate in an appropriate topic as arranged between the candidate and the coordinator of the program.

Industrial Courses

Short Courses

This last year, our short course entitled *COLORIMETRY: An Intensive Short Course for Scientists and Engineers* was again a success; 49 participants attended the June course. This three day course is designed to teach the effective applications of colorimetry to persons involved in coatings, textiles, polymers, reprographics, and electronic imaging. The course stressed instrumental measurements particularly useful for instrumental quality control. This course will be offered June 3-5, 1992.

Our newest industrial Course, *Principles of Color Reproduction: An Intensive Short Course* taught by Dr. R.W.G. Hunt was held in September. This course nicely complements our *COLORIMETRY* course. Dr. Hunt spends half of the course teaching about how color is formed using photographic, television, and reprographic imaging modalities. The *COLORIMETRY* course intentionally omits any information about color formation. This course will be offered October 14-16, 1992.

During 1992, two new advanced courses will be presented for the first time. The first course, *CRT Colorimetry for Image Displays*, will focus on CRT metrology and device independent characterization. The second course, *Psychophysical Techniques for Color and Imaging Sciences*, will focus on methods of visual scaling and experimental design. Both courses will be enrollment limited to facilitate in-depth laboratory sessions. We are very excited about these new courses; based on our recent interactions with industry, we have found a growing need for more information about these topics. These courses will be conducted on June 8-11, 1992.

The Munsell Laboratory's short courses for industry have and will continue to be a major part of the laboratories dedication to a useful interaction with industry.

The faculty of the Munsell Color Science Laboratory also instruct many seminars throughout the year at technical conferences, at RIT through other programs, and on site. Below is a list of these seminars from the past year.

1. *Colorimetry for Electronic Imaging*, presented as part of Imaging Science and Technology at Eastman Kodak Company, Rochester, NY, April, 1991. (1 day)
2. *Colorimetry for Electronic Imaging Systems* presented to Dupont Imaging,, Eagle Run, DE, May, 1991. (3 day)
3. *Color Reproduction Principles for Graphic Systems: Colorimetry Section*, presented by Imcotek, Inc., Boston, MA, June, 1991. (1 day)
4. *Colorimetry for Electronic Imaging*, presented to Xerox, El Segundo, CA, May 1991. (3 day)
5. *Colorimetry for Electronic Imaging*, presented to Xerox, El Segundo, CA, December, 1991. (2 day)
6. *Colorimetry for Electronic Imaging*, presented to Polariod Corporation, February, 1991. (1 day)

Site Visits to Rochester Institute of Technology

Representatives of the following companies visited to tour facilities and discuss color-related issues during 1991:

National Tsing Hua University, University of Rochester, Konica Corporation, Dainippon Ink & Chemicals, Inc., R.R. Donnelley & Sons, Inc., HunterLab, IBM-Canada, Eastman Kodak, Shelyn, Inc., Xerox Corporation, and Dupont Company.

Site Visits to Industry

Dr. Berns visited the following companies during 1991:

Eastman Kodak Company, Rochester, NY
Dupont Company, Eagle Run, DE
R.R. Donnelley & Sons, Incorportated, Lisle, IL
Fuji Photo Film Co., Ltd., Japan
Toyo Ink Mfg. Co., Ltd., Japan
Konica Corporation, Japan
Xerox Corporation, El Segundo, CA and Rochester, NY

Dr. Fairchild visited the following laboratories:

Eastman Kodak Copy Products Division, Rochester, NY
Eastman Kodak Desktop Color Imaging, Rochester, NY
Eastman Kodak Imaging Science Research Labs, Rochester, NY

Technical Reports

The following list Munsell Color Science Laboratory Technical Reports published to date. These reports contain various types of information and are written by faculty, staff, and students studying color science. The purpose of these reports is to provide additional information on subjects that are not appropriate for journal publications, either due to their information content or their length.

1. *Long-Term Calibration of a Diode-Array Radiometer,* Fairchild and Berns, May, 1986.

2. *The Present Status and Future Directions of the Development of the Munsell Color Science Laboratory as an Intermediate Calibration Laboratory for Spectrophotometry,* Fairchild, January, 1987.

3. *Munsell Color Science Laboratory Comments on the NBS Response to the Fourth CORM Report on Pressing Problems and Projected Needs in Optical Radiation Measurements,* Fairchild, January, 1987.

4. *Munsell Color Science Laboratory Comments on NCSL Information Manual for the Design of a Standards Laboratory,* Fairchild, January, 1987.

5. *Investigation of the Accuracy of Array Radiometry for Measuring Pulsed Radiation Sources,* Farrell and Fairchild, July, 1987.

6. *Report on 21st CIE Session,* Berns, October, 1987.

7. *Goniospectrophotometric Data for Pressed PTFE Primary Transfer Standard,* Fairchild and Daoust, October, 1987.

8. *Goniospectrophotometric Data for Pressed Barium Sulfate Primary Transfer Standard,* Fairchild and Daoust, October, 1987.

9. *Evaluation of the LMT C1200 Tristimulus Colorimeter,* Gorzynski, August, 1989.

10. *Characterization the Colorimetric Properties of a Flat-bed Scanner Using Multiple-Linear Regression,* A. North, December, 1990.

11. *Color Model Evaluation of a Thermal-Wax Printer,* R. Luciano, May 1991.

12. *CRT Metrology and Colorimetric Characterization Techniques,* R. Berns, M. Gorzynski, R. Motta, September, 1991.

Past Publications

The following is a list of previous articles published by faculty, staff, and students of the Munsell Color Science Laboratory:

1990

M.D. Fairchild, "Chromatic Adaptation and Color Appearance," *Ph.D. Dissertation, University of Rochester* (1990).

R.S. Berns and R.G. Kuehni, "What determines crossover wavelengths of metameric pairs with three crossovers?," *Color Res. Appl.* **15**, 23-28 (1990).

M.D. Fairchild, D.J.O. Daoust, J. Peterson, and R.S. Berns, "Absolute reflectance factor calibration for goniospectrophotometry," *Color Res. Appl.* **15**, 311-320 (1990).

M. E. Gorzynski and **R.S. Berns**, "Effects of ambient illumination and image color balance on the perception of neutral in hybrid image display systems,"*SPIE Proceedings* Vol. 1250, 111-118 (1990).

M.D. Fairchild, and P. Lennie, "Spatial and temporal properties of chromatic adaptation mechanisms," proceedings of OSA Annual meeting, 149 (1990).

1989

M.D. Fairchild, "A Novel Method for the Determination of Color Matching Functions," *Color Res. Appl.* **14**, 122-130 (1989).

D.H. Alman, **R.S. Berns, G.D. Snyder**, and W.A. Larsen, "Performance Testing of Color-Difference Metrics Using a Color Tolerance Dataset," *Color Res. Appl.* **14**, 139-151 (1989).

R.S. Berns and R.G. Kuehni, "Dependence of Crossover Wavelengths of Metameric Pairs on Colorant Absorption Properties," Color 89, *proceedings of the 6th Congress of the International Color Association*, 178-180 (1989).

1988

R.S. Berns and **R.J. Motta**, "Colorimetric Calibration of Soft-Copy Devices to Aid in Hard-Copy Reproduction," *proceedings SPSE 41st annual conference* 266-269 (1988).

A. Greenfield and **R.S. Berns**, "The Colorimetric Measurement of Color Cathode Ray Tubes Using a Tracor Northern TN-1710 Array Radiometer," *proceedings SPSE 41st annual conference* 270-271 (1988).

M.D. Fairchild and **J.O. Daoust**, "Goniospectrophotometric Analysis of Pressed PTFE Powder for use as a Primary Transfer Standard," *Applied Optics* 27, 3392 (1988).

M.D. Fairchild and P. Lennie, "Ganglion Cell Pathways for Rod Acuity," *proceedings of OSA Annual Meeting,* 80 (1988).

R.S. Berns and **K.H. Petersen,** "Empirical Modeling of Systematic Spectrophotometric Errors," *Color Res. Appl.* **13,** 243-256 (1988).

C.J. McCarthy, **E. Walowit,** and **R.S. Berns,** "Spectrophotometric Color Matching Based on Two-Constant Kubelka-Munk Theory," *Color Res. Appl.* **13,** 358-362 (1988).

R.S. Berns, M.D. Fairchild, and **M.M. Beering,** "The Quantification of Illuminant Metamerism for Four Coloration Systems vis Metameric Mismatch Gamuts," *Color Res. Appl.* **13,** 346-357 (1988).

R.S. Berns, D.H. Alman, **G.D. Snyder,** and W.A. Larsen, "Evaluation of Color-Difference Equations Using a Visual Color Tolerance Dataset," *Book of Papers, Nat'l. Tech. Conf., Tex. Chem. Col.,* 115-117 (1988).

1987

M.D. Fairchild and **R.S. Berns,** "Implementation of Recommended Ocular Exposure Thresholds for the Evaluation of Xenon Flashes," *J. Imaging Tech.* **13,** 8-13 (1987).

R.S. Berns and **F. Grum,** "Illuminating Artwork: Consider the Illuminating Source," *Color Res. Appl.* **12,** 63-72 (1987).

R.S. Berns, D.A. Alman, and **G.D. Snyder,** "Visual Determination of Color-Difference Vectors," *proceedings 21st session of the CIE, Vol. I,* 62-65 (1987).

F. Grum, M.F. Fairchild, and **R.S. Berns,** "Goniospectrophotometric Characteristics of White Reflectance Standards with respect to the CIE Normal/45 Geometry," *proceedings 21st session of the CIE,* Vol. I, 134-137 (1987).

N. Burningham and **R.S. Berns,** "Analysis of Color in Electrophotographic Images," *proceedings SPSE 40th annual conference,* 90-93 (1987).

R.J. Motta, "Colorimetric Errors Due to the Microstructure of Additive Color Imaging Systems," *proceedings SPSE 40th annual conference,* 94 (1987).

M.D. Fairchild, "Development of Goniospectrophotometric Transfer Standard," *proceedings of OSA Annual Meeting,* 132 (1987).

C.J. McCarthy, **E. Walowit,** and **R.S. Berns,** "An Algorithm for the Optimization of Kubelka-Munk Absorption and Scattering Coefficients," *Color Res. Appl.* **12,** 340-343 (1987).

1986

R.S. Berns, "A FORTRAN Program for Predicting the Effects of Chromatic

Adaptation on Color Appearance based on Current CIE Recommendations," *Color Res. Appl.* **11**, 82-88 (1986).

1985

F. Grum, M. Pearson, and N. Scharpf, "Standards and Standardization in Optical Radiation Measurements," *TAGA Proceedings*, 472-486 (1985).

M.D. Fairchild and **F. Grum**, "Thermochromism of Ceramic Reference Tiles," *Applied Optics* **24**, 3432-3433 (1985).

R.S. Berns, "Metameric Mismatch Limits of Industrial Colorants," *Mondial Couleur 85, proceedings of the 5th Congress of the International Color Association*, paper 40 (1985).

F. Grum and **R.M. Miller**, "Spectrogoniophotometric Properties of Standard Reference Materials," *Mondial Couleur 85, proceedings of the 5th Congress of the International Color Association*, paper 53 (1985).

Facilities

The Munsell Color Science Laboratory is housed on the third floor of the Chester F. Carlson Center for Imaging Science, at the Rochester Institute of Technology. This a facility, dedicated on October of 1989 in the memory of Chester Carlson, inventor of Xerography, and will serve as a comprehensive center for education and research in imaging science. Color science is one of several major research themes of The Center for Imaging Science. The main laboratory contains many color measuring instruments, while small rooms off the main area are dedicated to specific tasks. These areas contain low and high resolution image processing and display systems with input and output devices, spectroradiometric and photometric measurement equipment and visual apparatus. One room was specially designed for high accuracy optical radiation measurements and houses several spectrophotometers used for research and calibration services, and goniospectrophotometric research. Research on color vision and image perception is performed in another laboratory located on the same floor. This laboratory contains computer systems optimized for visual display and psychophysical experimentation, and other apparatus for the study of vision. Color Science research and education through the color science master's degree program and industrial seminars is conducted in the Munsell Color Science Laboratory and associated laboratories. The current list of equipment is given below.

Optical Properties of Materials

BYK-Gardner Colorgard System 1000 Colorimeter
0/45
Donation by BYK-Gardner

BYK-Gardner Glossgard II
20, 60 and 85 degree
Donation by BYK-Gardner

BYK-Gardner Spectrogard Spectrophotometer
d/0, 380-720nm, grating monochromator, color matching software
Donation by BYK-Gardner

BYK-Gardner The Color Machine Spectrophotometer
380-720nm, 45/0, 32 diode array detector, color matching software
Donation by BYK-Gardner

BYK-Gardner The Color Sphere Spectrophotometer
380-720nm, 4d/0, 32 diode array detector, color matching software
Donation by BYK-Gardner

Cary 17D Spectrophotometer
186-2650 nm range, digital and analog
Donation by Eastman Kodak Co.

Cosar Pressmate I Densitometer
Hand held, Status T, reflection
Donation by Cosar Corp.

Cosar 75 CompuPlus Densitometer
Status A and M, transmission/reflection
Donation by Cosar Corp.

Datacolor Intl. Chroma-Sensor CS-5 Spectrophotometer
400-700 nm, d/0, interference wedge mono
Chroma-Calc color matching software for paints, textiles, and inks
Decorator 300 software
VCS-11 software
Donation by Datacolor Intl.

Diano Match Scan II Spectrophotometer
380-1000nm, d/0, reversible optics, grating monochromator
Donation by MiltonRoy APD

General Electric Recording Spectrophotometer
380-700nm, 0/d, analog,
D & H tristimulus integrater

HunterLab D25A-9 Tristimulus Colorimeter
45/0, 4 filtered detectors, Ill. C
Donation by Hunter Associates Laboratory

HunterLab D25D-2 Tristimulus Colorimeter
45/0, 4 filtered detectors, Ill. C
Donation by Hunter Associates Laboratory

HunterLab Dori-gon Meter D47-6
Abridged Goniophotometer
Donation by Hunter Associates Laboratory

HunterLab Labscan Spectrophotometer
400-700nm, 0/45, interference-wedge mono
Donation by Hunter Associates Laboratory

HunterLab MiniScan Spectrophotometer
Portable, 400-700nm, 45/0
Donation by Hunter Associates Laboratory

HunterLab Modular Model D48-7 Gloss Meter
20 and 60 degree heads
Donation by Hunter Associates Laboratory

HunterLab UltraScan SpectroColorimeter
375-750nm , d/0, 76 diode-array detector
Donation by Hunter Associates Laboratory

IBM Model 9420 Spectrophotometer
190-900nm, transmission/reflection
Donation by IBM

Macbeth 1500/Plus Spectrophotometer
400-700nm, d/0, 16 diode-array detector, Optiview, Optimatch, CIE-to-Munsell
Donation by Macbeth

MCSL Goniospectrophotometer
Variable illumination and viewing angles
Partally donated by Eastman Kodak Co.

Milton Roy Color Mate HDS Spectrophotometer
400-700nm, 45/0, 16 diode array detector
Donation by MiltonRoy APD

Milton Roy ColorScan Spectrophotometer
350-780nm, d/0, grating monochromator
Donation by MiltonRoy APD

Milton Roy ColorScan/45 Spectrophotometer
350-780nm, 45/0, grating monochromator
Donation by Milton Roy APD

Minolta Chroma Meter CR-221 Colorimeter
compact, 45/0, D65, C
Donation by Minolta Corp.

Minolta CM-1000 Spectrophotometer
Portable, 400-700nm, d/0, diode array detector
Donation by Minolta Corp.

Minolta CM-2002 Spectrophotometer
Portable, 400-700nm, d/0, diode array detector
Donation by Minolta Corp.

Optronic 746-D Spectrophotometer
280-2500nm, 0/d, grating monochromator

Photodyne 99XL Densitometer
Portable, transmission/reflection
Donation by Photodyne

X-Rite 968 Spectrophotometer
400-700nm, 0/45, portable
Donation by X-Rite

Radiometry

LMT C1200 Colorimeter
17 filtered detectors, 2° obs.
Donation by LMT

Minolta Chroma Meter II Incident Colorimeter
Hand held, 2° obs.
Donation by Minolta Corp.

Minolta Chroma Meter CS-100 Colorimeter
Hand held, spot reflex viewing
Donation by Minolta Corp.

Minolta Color Analyzer CA-100Colorimeter
4 filter, designed to measure CRT, 2° obs.
Donation by Minolta Corp.

Optronic Model 740 Spectroradiometer
280-1100 nm range, double monochromator, calibrated detector
Donation by Optronic Laboratories Inc.

Photo Research PR-703A Spot SpectraScan Spectroradiometer (2)
256 diode-array, Pritchard optical system
Donation by Photo Research

Photo Research PR-1500 SpotMeter Radiometer/Photometer
PMT, Pritchard optical system
Donation by Photo Research

Schoeffel Monochromator (2)
blazed at 500nm and 300nm

Tracor Northern DARSS Spectroradiometer
240-870 nm range, 512 diode-array

Partial List of Visual Apparatus

Breneman Visual Colorimeter
Donation by Eastman Kodak Co.

Color Curve Color Communication System
Master and gray & pastel atlases
Donation by Color Curve

Dianolite Viewing Booth (3)
D65, A, and UV
Donation by Milton Roy APD

D & H Color Rule (3)
Metameric slide rule

Datacolor Intl. VCS-10
Maxwell disk colorimeter
Donation by Datacolor Intl.

Datacolor Intl. Tru-Vue Viewing Booth
D65, A, CWF, and UV
Donation by Datacolor Intl.

Farnsworth-Munsell 100 Hue Test (2)
Color discrimination test

Graphiclite Show-Off Portable Viewing Booth
D50, reflection and transparency viewing

ICI Color Atlas
Color order system

ISCC Color Aptitude Test
Color discrimination and aptitude test

Isochromatic Plate Color Blindness Charts
Versions by Ishihara, Dvorine, and American Optical Co.

Japan Color Research Institute Chroma Cosmos 5000
Munsell based color order system

Lovibond Tintometer Visual Colorimeter (2)
Model E and Mark 3, Subtractive versions.
Donation by Tintometer Co.

Macbeth SpectraLight Viewing Booth
D65, CWF, horizon, and narrow band fluorescent

Macbeth SpectraLight Viewing Booth
D75, CWF, Horizon, and UV
Donation by Macbeth

MCSL Visual Colorimeter
CRT light source, mouse controlled

Munsell Book of Color
Glossy and matte editions
Donation by Munsell Color Company

Nagel Anomaloscope
Protan and deuteran test

Natural Color System Atlas
Color order system.
Donation by Swedish Standards Institute

Opthalmoscope
Donation by Welch-Allyn Inc.

OSA Uniform Color Scales
Color order system

Color Display and Reproduction

Barco "Calibrator" Color Video Monitor
19V, black dot mask,
Donation by Barco Industries

HP 9000/375TSRX Computer System
HP 9000/375 host computer
HP 98731 graphics accelerator,
HP 98550 graphics processor, 1280x1024x8
Donation by Hewlett-Packard

HP 98745A Color Video Monitor
Sony Trinitron, 19V
Donation by Hewlett-Packard

HP 98789 Color Video Monitor
Sony Trinitron, 16V
Donation by Hewlett-Packard

HP Paintjet Color Printer
Donation by Hewlett-Packard

Howtek Scanmaster Color Scanner (Sharp JX450)
300DPI flat bed color scanner

Javelin JE2362 CCD Camera.
RS-170 sync, 576x485

Kodak SV-6510 Still Video Printer
Color dye-diffusion printer

Konica VP-1000 Color Video Printer
1024x1248, 24 bit, photographic printer
On loan from Konica Corporation

Matrix ProColor Film Recoder
35mm digital film recorder

Macintosh II Computer System
Sony 13V, 24 bit

Pixar II Computer System
Sun Microsystems 3/160HM, host computer,
Pixar II Image Computer 2M Pixels x 48
60MB

Pixar II Computer System
Sun Microsystems 3/260HM, host computer,
Pixar II Image Computer 10M Pixels x 48,
60MB
Donation by R. R. Donnelley

Sony GDM-1950 Color Video Monitor
19V, Trinitron CRT

Sony PVM-1942Q Digital Color Video Monitor(2)
19V, Trinitron CRT, RS-170, RGB, NTSC,
PAL, SECAM

Tektronix 650HR-C Color Video Monitor
13V, Trinitron CRT,
Donation by Tektronix

Tektronix 690SR Color Video Monitor
19V, dot mask
Donation by Eastman Kodak Co.

Tektronix Color Quick Ink-jet Printer
216 DPI, CMYK ink system
Donation by Tektronix

NEXTdimension Computer System
4m pixels x 32
Phillips color 17V, 1120x832x32 monitor

For More Information

For more information concerning the activities of the Richard S. Hunter Professor or the Munsell Color Science Laboratory, please contact:

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