RICHARD S. HUNTER PROFESSORSHIP

MUNSELL COLOR SCIENCE LABORATORY

ANNUAL REPORT
1990

Rochester Institute of Technology

Center for Imaging Science
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Dedicated to the Memory
of
Richard S. Hunter

1909-1991

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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

This past year we were part of RIT history: The first Ph.D. degree offered at the Institute began this Fall. As part of the Center for Imaging Science, we have toiled along with the rest of the Center in establishing a doctoral degree; the first students arrived this September. As time passes there will be doctoral dissertations on color related topics. We are all very excited about the prospect of advising student research more fundamental in nature and lengthier in duration than typical masters' theses.

Within the Laboratory, computers and spectrophotometers have been the primary focus. ACS Datacolor, Hunter Laboratories, Macbeth and Photo Research all upgraded their color measurement software. Loading and configuring the new software has been time consuming. Lisa Reniff has been working very hard to optimize the operating systems of each computer and make their use easy for all of us. All of the new software will enhance our teaching and research. We also received three new spectrophotometers: ACS Datacolor donated a CS-5; Hunterlab upgraded our Labscan and donated an Ultrascan; X-rite donated a portable 968 spectrophotometer; Minolta donated several colorimeters. All of our color measuring systems are now state-of-the-art. The novel ACS Datacolor system combines traditional colorimetry and colorant formulation with color imaging; in addition to the spectrophotometer, a colorimetrically characterized IBM PC VGA Video Monitor and Tru-Vue light booth were also donated forming a unique type of hybrid imaging system. We are looking forward to using all the new systems and we are thankful to Lisa for insuring their daily operational effectiveness.

We now have three UNIX workstations for use in color reproduction and color appearance research. One system is a SUN 3/260 and Sun TAAC graphics board. The second is a Sun 3/160 and Pixar II image computer. The third and most recent is a Hewlett Packard 9000 workstation, a generous donation from HP Research Laboratories. All are full color and all have different advantages and disadvantages relative to our research objectives. We also have several color input and output devices. The three workstations and peripherals combine together via Ethernet to form a formidable color-image-processing network. Mark Fairchild, Mark Gorzynski, Po-cheih Hung, and Mike Stokes have been working on various aspects of systems architecture, image manipulation, image presentation, and colorimetric characterization. A number of research projects are underway. It has been very difficult to estimate programming time and predict where the pitfalls lie. Because of everyone's enthusiasm and dedication, our progress has been substantial. We have entered a new age of color research. Equipment of this type will enable us to study color perception within the gestalt of scenes rather than several uniform color samples viewed against a neutral background.

Another imaging system was put together for use in our color modeling course. We added a dye diffusion printer and monochrome camera to our low-

resolution Number Nine based PC system. Students will colorimetrically characterize a broadcast television monitor, printer, and camera (with student selected color filters) to learn how to achieve colorimetric color reproduction. Mark Gorzynski has nearly completed the system software and we're looking forward to "test driving" it spring quarter. The system will also be used in research where texture will be analyzed colorimetrically.

This past year was our first entire year with a full-time secretary. Colleen McCabe has developed filing systems for the Munsell Color Science Laboratory archives, Mark Fairchild, and myself. She has also computerized our calendars and our mail lists. All of the staff and faculty within the Munsell Color Science Laboratory now are networked together. We are slowly cutting down on the amount of paper we use. Perhaps Colleen's greatest contribution has been taking over the organization of our industrial seminars. Besides handling all the registration, she coordinated the re-writing of our *Colorimetry: An Intensive Engineers* course notes. The result is a 250 page document with all original graphics. For most of us, this was the first time we saw Munsell hue and chroma contours plotted in various color spaces at value levels different than value 5. The large increase in figures has made our teaching much more efficient. Perhaps this is the first step to a text on applied colorimetry!

"Color WYSIWYG" (what-you-see-is-what-you-get) became part of our vocabulary. We have formed a hypothesis that the first step to achieving acceptable color reproduction quality in pre-press and desktop publishing environments is to achieve colorimetric color reproduction. This necessitates colorimetric characterization of imaging devices. Our visiting scientist from Konica Corporation, Mr. Po-Chieh Hung, has developed extensive software utilizing look-up-table, interpolation, and extrapolation techniques. In addition to software, Po-Chieh is writing articles documenting his techniques. We are very excited about having this technique available to us. There are many devices that do not lend themselves readily to analytical characterization; in these cases empirical approaches are an attractive practical alternative.

Color measurement precision and accuracy was another area of research. Xerox provided partial support in the development of an industrial measurement assurance program for reflectance factor measurements. This project will implement the many theoretical studies we have performed on modeling instrument errors. Lisa Reniff and Mark Fairchild have been leading this effort. During May, the Council for Optical Radiation Measurements held their annual meeting here in the Center on the general topic of measurement uncertainty. Three papers were presented by faculty and staff of the Munsell Laboratory. The conference certainly helped focus our thinking and research objectives relative to standardization activities.

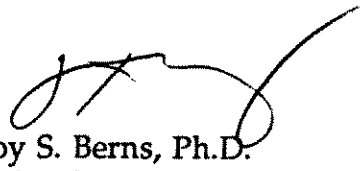
Funding is an ongoing concern in an academic environment. This year, we were very fortunate in establishing two industrial scholarships. Hewlett Packard,

Corvallis Division and R.R. Donnelley & Sons are both supporting master's level research concerned with color reproduction. We are very pleased to be interacting with industry at a research level. Ken Parton's research on modeling the spectral and colorimetric properties of an ink-jet printer is supported by HP. Ken spent the last two summers working for HP as a summer intern. Donnelley is supporting Mike Stokes' research on colorimetrically tolerancing pictorial images. Mike is also this year's Franc Grum Memorial Scholar. We were also awarded the Kollmorgen Foundation scholarship for graduate research in color science. Amy North was awarded the scholarship to study observer metamerism using a visual colorimeter developed in the Munsell Laboratory by Mark Fairchild. I am confident that these projects will be completed successfully and timely and that we can attract more scholarships of this type in the future.

Our students were also very interactive with industry. Three of our graduate students and one undergraduate worked in industry last summer. Besides Ken Parton, Amy North worked at Xerox, Seth Ansell worked at Kodak, and Rob Luciano worked at Tektronix. Our new students have already expressed an interest for the coming summer.

As always, our successes would not be possible without the strong support from the color science community. Mrs. Elizabeth Hunter continues to personally support many of my activities while Mr. Richard Hunter was a constant source of inspiration. Sadly, Mr. Hunter passed away January 16, 1991. I feel very lucky to have had such a unique relationship with him. After each visit, I was always renewed. He helped me see the "big picture" of the importance of color science education. I will carry his memory and his enthusiasm for color with me as I pursue the science, appearance, and technology of color.

The instrument manufacturers have been very supportive with equipment, software, and service. Industry supports us with cash donations, scholarships, research contracts, and equipment. We continue to receive support from PPG, Tektronix, Mobay, and 3M. This year we added two new names to our monetary donors, Sherwin Williams and Macbeth. Both companies have significant presence in the color community and we are grateful for their support. Above all, my colleague Mark Fairchild, my staff Lisa Reniff, Mark Gorzynski, and Colleen McCabe, and my students gave me the most support. Without their dedication, there would be no magic.



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

January, 1991

Staff Activities

The following reports summarize the activities during 1990 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.

The most significant event of the year for me came early in 1990. I completed my Ph.D. last March. I'll take this opportunity to thank all of you who supported me in the years I was working toward the degree, especially the unprecedented personal support given me by Roy and Lisa. The next big event was my promotion from Instructor to Assistant Professor. I'm looking forward to many exciting years in the Munsell Lab.

I spent the summer working on various research projects and papers. The most fun was generating 3-dimensional color representations of the color-difference tolerances from Roy's work on one of our computer imaging systems. I wrote a few papers on topics like goniospectrophotometric standards, error propagation, color reproduction, and chromatic adaptation. They should be appearing soon in a journal near you.

I also joined my first CIE committee (TC1-27, Specification of Color Appearance for Reflective Media and Self-Luminous Display Comparisons) and became the OSA delegate to ISCC. I am looking forward to becoming more involved in such activities.

My research plans for the future revolve around image reproduction problems. I am interested in modeling the color appearance of image elements and objects in scenes. This work involves many fundamental aspects of color vision and color measurement and will assure that I'm involved in many areas that fall under the umbrella of color science.

Another of my enjoyable responsibilities is teaching. Presently, I am teaching an interesting variety of courses that includes 4 graduate courses; Vision and Psychophysics, Color Science Seminar, Optical Radiation Measurements, and Imaging Science Laboratory, and 2 undergraduate courses; Vision, Color, & Psychophysics and Macroscopic Properties of Imaging Systems.

Lastly, I'd like to thank of the supporters of the Munsell Color Science Laboratory for making everything in this annual report possible.

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

The past year has been one of steady growth. I have continued to develop the 45/0 geometry reflection standardization ability of the laboratory and have looked into some of the problems present in the standardization process. These include the propagation of error through the calibration chain to the end user and how uncertainty should be reported in spectrophotometric measurements. I have also examined the effect of instrumental error on commonly used CIELAB calculations. In the past year, a measurement assurance program (MAP) has been set up, with the assistance of Xerox Corp., for visible 45/0 geometry reflectance measurements.

The laboratory has grown in the past year in terms of people and equipment, primarily due to the generosities of many of our industrial friends. With this growth, has found a portion of my time trying to "catch-up" with maintenance, installation and knowledge of software and hardware. As always, it is extremely enjoyable to help the graduate students in learning the basics, and exploring the new territory in their thesis work.

Mark E. Gorzynski, Associate Scientist, (716) 475-7186
A.S., Graphic Communications, Villa Maria, 1979.
A.S., Fine Arts, Villa Maria, 1980.
A.S., Photography, Villa Maria, 1981.
B.S., Imaging Science, Rochester Institute of Technology, expected 1991.
M.S., Imaging Science, Rochester Institute of Technology, expected 1991.

As always there was a lot to do last year in an exciting place like the Munsell Color Science Laboratory. Currently the lab supports 3 UNIX workstations dedicated to use in color appearance and color reproduction research. This being a new area for the lab, I spent quite a bit of time working on systems administration, studying the feasibility of various environments for performing color appearance research, and creating research related software. Some of the software created includes color measurement instrumentation interfaces, basic color transformations, image format translation software, and basic image statistics. This low level work should pave the way for many projects to come.

Also new for the lab is a room dedicated for student use in color modeling classes. Getting this lab together involved investigation of CCD cameras, as well as individually ordering, installing, and customizing about 30 major hardware and software components. Currently I am continuing with creating custom software for student use in running laboratory experiments.

Roy and I also continued our work last year on display colorimetry. This work should culminate this spring with several articles. This work is also important to Roy's CIE Technical Committee. I have been helping Roy with this committee and am co-chair of ISCC Project Committee 32, Image Technology.

Po-Chieh Hung, Visiting Scholar, (716) 475-7193
B.S., Electronic Engineering, Waseda University, 1981.
M.S., Control Engineering, Waseda University, 1983.
Working for Konica Corporation from 1983 to present.

This past year was the most wonderful time in my stay, also in my life. As the language barrier has been getting removed, and my research has proceeded very well. The only bad thing is that I have to return to Japan in March, 1991. I am going to miss the good facilities and people in the Munsell Color Science Laboratory.

My recent work was to find an appropriate color space for color reproduction of electronic imaging. I tortured nine folks in a dark room for 50 hours in total to find constant hue lines. Lisa kindly told me that "torture" means my psychological experiment, and let me expand my English vocabulary, precisely. But I really appreciate their contributions.

I am going to work on color reproductions in Konica, too. Someday I would like to see you again with our devices, on which my colorimetric calibration work is applied.

Students

The following are students studying in color science.

FULL TIME GRADUATE

Mr. Seth Ansell, M.S. Candidate, Color Science

B.S., Imaging Science, Rochester Institute of Technology, 1989.

Mr. Yan Liu, M.S. Candidate, Color Science

B.S., Imaging Science, Rochester Institute of Technology, 1989.

Ms. Amy North, M.S. Candidate, Color Science

B.S., Physics, Shandong Unifersity, 1982.

M.S., Color Science, Shandong Textile Engineering College, 1984.

Mr. Brant Nystrom, M.S. Candidate, Color Science

B.S., Imaging Science, Rochester Institute of Technology, 1990.

Mr. Ken Parton, B.S./M.S. Candidate, Imaging Science

A.S., Engineering Science, Onondoga Community College, 1986.

Mr. Jason Peterson, B.S./M.S. Candidate, Imaging Science

A.S., General Science, William Rainey Harper College, 1982.

A.A., Graphic Design, William Rainey Harper College, 1982.

Ms. Elizabeth Pirrotta, M.S. Candidate, Color Science

B.S., Color Science, Philadelphia College of Textiles and Science, 1990.

Mr. Brian Rose, M.S. Candidate, Color Science

B.S., Color Science, Philadelphia College of Textiles and Science, 1990.

Mr. Mike Stokes, M.S. Candidate, Color Science

B.S., Mathematics, University of Texas at Austin, 1989.

PART-TIME GRADUATE

Mr. Jim Adams, M.S. Candidate, Imaging Science

B.S., Physics, Monmouth College, 1979.

B.S., Electronic Device Physics, Monmouth College, 1979.

M.S., Optics, University of Rochester, 1984.

Mr. Jeffrey Wang, M.S. Candidate, Color Science

B.S., Graphic Arts, Chinese Culture University, 1982.

M.S., Imaging Science, Rochester Institute of Technology, 1988.

FULL-TIME UNDERGRADUATE

Mr. Todd Huck, B.S. Candidate, Imaging Science

Mr. Robert Luciano, B.S. Candidate, Imaging Science

Mr. Chris Reilly, 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. This year we received a large number of upgrades and new equipment.

This year we added a new category of funding: scholarships. We are grateful that industry recognizes the importance of student scholarship and non-proprietary research. Each scholarship of $25,000 or more supports a single student. Scholarship donations are project specific.

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

SCHOLARSHIPS

Franc Grum Memorial.....$1,000
Hewlett Packard.....$25,000
Kollmorgen Foundation.....$30,000
R.R. Donnelley & Sons.....$32,500

UNRESTRICTED RESEARCH GRANTS AND GIFTS

3M Company.....$5,000
Elizabeth Hunter.....$10,000
Macbeth Corporation.....$5,000
Mobay Corporation.....$2,500
PPG.....$5000
Sherwin Williams
Consumer Division.....$5,000
Automotive Division.....$5,000
Tektronix Incorporated.....$10,000

DEVICES

Donor	*Device*	*Value*
ACS Datacolor	2018 Color Control System	$90,000
	IBM Model II 55 SX-031	
	IBM Pro printer	
	CV/VCS-11 Package	
	CS-5 LAV/SAV/USAV Spectrophotometer	
	Chroma-calc ink, textile, paint software	
	Decorator 300 software	
	VCS-10 Color Simulator	
BYK Gardner	Software upgrades	$1,000
Color Association of US	Color Compendium	$50
Hewlett Packard	9000/375 TSRX workstation	$80,000
Hunter Laboratories	UltraScan SpectroColorimeter	$25,000
	Upgrade on LabScan SpectroColorimeter	$2,500
LMT	The Photonic Directory	$145
Macbeth Corporation	Optiview,Optimatch, and Munsell conversion software	$21,000
	Repairs on Spectrophotometer	$1,000
Milton Roy	Color Mate Spectrophotometer	$14,000
Minolta Corporation	Chroma Meter CR0221 Colorimeter	$17,650
	Chroma Meter II Incident Colorimeter	
	Chroma Meter CS-100 Colorimeter	
	TV Color Analyzer TV-2160 Colorimeter	
Photo Research	SpectraView software upgrade	$7,350
Munsell Color Company	Munsell Color Samples	$350
Tektronix	Colorquick Ink-jet printer	$2,620
X-Rite Incorporated	Portable 968 Spectrophotometer	$8,950

Research Contracts:

E.I. Du Pont de Nemours, Inc.

Xerox Corporation

Research and Development

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 14 and 22 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

[Department of Energy, MCSL, Center for Imaging Science Industrial Associates, National Institutes of Health, Tektronix Corp.]
Mark Fairchild

New models for the prediction of corresponding colors under various conditions and the prediction of color appearance in complex image displays are being developed and implemented. These models consider the spectral, spatial, and temporal properties of chromatic adaptation that are also under investigation. The adaptation model will be reported at the 1991 CIE session and will appear in *Color Research and Application* in 1991.

Measurement Assurance Programs for Spectrophotometry

[Xerox Corp., MCSL]
Lisa Reniff, Mark Fairchild, Roy Berns

Measurement assurance programs (MAPs) are being developed for 45/0 and d/0 spectrophotometry. These programs will allow subscribers to measure a small set of tiles and then return the data to MCSL for evaluation. The subscribers will then receive a report indicating the accuracy of their instrument and possible systematic errors it might be suffering from. The 45/0 MAP should be available early in 1991.

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. Visual data are being collected to test the model independent from the data that were used to generate it.

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, we will be preparing three color charts, one of textiles, one dyed paper, and one using artists' acrylic paints. The charts will be reproduced using a photographic transparency system, a negative-positive system, and a four-color proofing system. The reproductions will be measured colorimetrically. The data will be entered into a color image processor interfaced to a colorimetrically characterized film recorder. Slides will be produced that are colorimetrically accurate and demonstrate the effects of photographic-observer metamerism. Separations made from these images should demonstrate metamerism. A tutorial article will be prepared that includes these images and a talk will be presented at the 1991 ISCC annual meeting.

SAS-Based Color Formulation Software
[MCSL, RSHP]
Roy Berns, Yan Liu

Computer colorant formulation can be thought of in terms of multiple-linear regression. In our color modeling course, the mathematics of formulation are taught but due to time constraints, students have difficulties implementing the theory in laboratory experiments. As an aid, we have written single constant and two constant Kubelka-Munk color matching software using the SAS statistics package. The software will minimize either tristimulus values or spectral differences between the standard and the formulation. The advantage of this software over commercial formulation software is the statistics output including ANOVA tables. Software of this type can be easily modified to test different forms of K-M besides single and two constant opaque models.

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

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.

Color Tolerancing 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. An average color difference for each image element is not a good measure of the overall change in the reproduction since it ignores possible changes in image parameters such as contrast. 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 will provide useful measurements of how close images have to be colorimetrically to be indistinguishable. These data will be useful in practical applications of color reproduction and in the evaluation of color appearance models. This project is the M.S. thesis topic of Mike Stokes.

Colorimetric Evaluation of Color Quantization in Digital Image Displays
[MCSL]
Todd Huck, 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.

Effect of Ambient Illumination and Image Color Balance on the Perceived Neutral-Point in Hybrid Imaging Systems
[Franc Grum Memorial Scholarship, MCSL, RSHP]
Mark Gorzynski, Roy Berns, Mark Fairchild

This project involves the examination of the various viewing parameters that affect the perception of neutral in hardcopy and softcopy image displays. Observer's were asked to choose achromatic-appearing stimuli under various conditions using a softcopy image display, hard-copy samples, and combinations of the two. The visual experiments have been completed and the results show some interesting differences in the color perception of softcopy displays, real objects, and renderings of real objects on softcopy displays. This project also serves as Mark Gorzynski's M.S. thesis. During the coming year, an article will be prepared for *Color Research and Application*.

Visual Determination of Color Difference Tolerances
[E.I. du Pont de Nemours Automotive Products Department]
Roy Berns, Lisa Reniff

An ongoing project aimed at generating a data set of equal perceptual color differences of industrial size. Phase II of visual experiments has been completed and the results of the first two phases have been combined. An article describing the research was prepared and submitted to *Color Research and Application*. The article is currently being reviewed. Aspects of the research will also be presented at the CIE quadrennium in Melbourne.

Color Difference Modeling
[E.I. du Pont de Nemours 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.

Modeling of Systematic Spectrophotometric Errors
[Xerox Corp., MCSL, RSHP]
Roy Berns, Lisa Reniff

Systematic errors in spectrophotometric measurements have been modeled and corrected using a linear regression technique. This technique can significantly improve measurement accuracy and inter-instrument agreement. Work continued on this project in the past year to improve our ability to implement this technique and to apply it to other instruments in a more general sense.

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

Software is being 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 will allow 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.

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

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 compression when it is desired to keep hue constant. These data might also serve as valuable test data for color appearance models.

Image Quality as a Function of Aspect Ratio for TV Displays
[MCSL]
Brant Nystrom, Mark Fairchild

This is an undergraduate research project aimed at studying the effect of image aspect ratio on the perceived quality of CRT images. Proposals for HDTV include changes in the aspect ratio based on the assumption that these changes improve image quality. However, surprisingly little research on this issue has been performed. The results have been compiled and a journal article is in preparation.

CRT Colorimetry
[LMT, Barco Ind., Minolta Corp., MCSL, RSHP]
Roy Berns, Mark Gorzynski

CRT displays are heavily used in our laboratory for psychophysical experiments. In order for these experiments to be successful, one must have accurate knowledge of the stimulus being displayed. This requirement has led to a tremendous effort in the Munsell laboratory aimed at measuring and modeling the colorimetric characteristics of CRT image displays. Work in the past year has centered around gathering together results of the many measurements and tests that have been performed and generating a journal article on this topic.

Effect of Luminance Level and Experimental Design on the Perceived Chroma of Munsell Samples
[RSHP]
Jason Peterson, Roy Berns, Mark Fairchild

This project's aim is to measure the changes in perceived chroma and possibly colorfulness as a function of adapting luminance level for simulated daylight illumination. This phenomenon is often referred to as the Hunt effect. The experiment will be carried out with several different techniques to assess their influence on the results. These include haploscopic matching, memory matching,

successive inspection and simultaneous inspection. These data are being used to test various color appearance models. Jason is currently putting the finishing touches on his thesis and preparing an article on this work.

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

This project is designed to measure inter- and intra-observer variation in the measurement of color matching functions and will serve as Amy North's M.S. Thesis. Much time has been spent optimizing and calibrating the visual colorimeter. Measurements of color matching functions will begin soon and will utilize an abridged method reported previously. In addition, the measurements will be compared with similar ones that were made this past summer using the National Research Council (NRC) trichromator in Ottawa, Canada.

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

Ken Parton spent the summer and fall of 1990 working for HP Corvallis Division where the initial plans for this M.S. thesis project were developed and much of the work started. The aim is to develop an analytical model capable of predicting the spectral reflectance of ink-jet printer output for various system parameters and input. This project is well underway and should be completed in the coming year.

Modeling the Spectral Reflectance of Thermal-Wax Printer Output
[MCSL]
Rob Luciano, Roy Berns

Rob Luciano spent the summer of 1990 working for Textronix in Beaverton, Oregon. He came back with the interest of learning more about color printers. A senior project was developed where Rob will test the performance of Kubelka-Munk and Neugebauer theories in predicting the colorimetric properties of a Tektronix thermal-wax printer. Rob will write software and also use the ACS Datacolor colorant formulation system.

A Neural Network Model of Color Appearance
[MCSL]
Chris Reilly, Mark Fairchild

Artificial neural networks have been used to model many interesting phenomena. This project was designed to investigate the plausibility of using such models to predict color appearance. A successful model was developed for very simple viewing conditions. Currently, a visual experiment is being performed as a senior research project to collect some appearance data to test this model. In addition, the possibility of using this type of model for CIE-to Munsell conversion is being investigated.

1990 Publications

The following is a list of reviewed articles and paper or abstract proceedings published or accepted for publication by faculty, staff and students of the Munsell Color Science Laboratory (listed in bold) during 1990. Past publications are listed beginning on page 22.

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, "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).

M.D. Fairchild, "A Model of Incomplete Chromatic Adaptation," *Color Res. Appl.* **16,** in press (1991).

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

R.S. Berns, "A color tolerance feasibility study comparing CRT generated stimuli with an acrylic-lacquer coating," *Color Res. Appl.* **16,** in press (1991).

1990 Presentations

R.S. Berns, "The Effects of Ambient Illumination and Image Color Balance on the Perception of Neutral in Hybrid Image Display systems," Hewlett Packard Research Laboratories, Palo Alto, California, January.

R.S. Berns, "A Review of Ongoing Research at the Munsell Color Science Laboratory with a focus on chromatic adaptation experiments," Tektronix, Beaverton, Oregon, January.

R. S. Berns, "The Effects of Ambient Illumination and Image Color Balance on the Perception of Neutral in Hybrid Image Display systems," DX Imaging Second Biennial Color Symposium, Lionville, Pennsylvania, February.

M.D. Fairchild, "A Model of Incomplete Chromatic Adaptation," Inter-Society Color Council Annual Meeting, Cleveland, Ohio, April.

M.E. Gorzynski, "The effects of ambient illumination and image color balance on the perception of neutral in hybrid mage display systems," Inter-Society Color Council Annual Meeting, Cleveland, Ohio, April.

L. Reniff, "Colorimetric Methods of Evaluating Systematic Spectrophotometric Errors," Inter-Society Color Council Annual Meeting, Cleveland, Ohio, April.

R. S. Berns, "The Effects of Appearance Attributes on Visual and Instrumental Color Tolerances Using Computer Generated Imagery," Society for Color and Appearance Instrumentation Conference, Cleveland, Ohio, April.

P. Hung, "Pictorial examples of CIELAB and CIELUV hue constancy," Inter-Society Color Council Annual Meeting, poster presentation, Cleveland, Ohio, April.

Y. Liu, "Negative feedback control of the visual system and systematic color vision model," Inter-Society Color Council Annual Meeting, poster presentation, Cleveland, Ohio, April.

M.D. Fairchild, "A Query on Error Propagation in Optical Radiation Measurements," Council for Optical Radiation Measurements Annual Meeting, Rochester, New York, May.

R.S. Berns and L. Reniff, "Methods of Transferring the Scale of Spectral Reflectance Factor for 45/0 Geometry," Council for Optical Radiation Measurements Annual Meeting, Rochester, New York, May.

M.D. Fairchild, "Color Appearance in Softcopy Image Displays," Society for Imaging Science and Technology Annual Meeting, Rochester, May.

R.S. Berns, "The Effects of Ambient Illumination and Image Color Balance on the Perception of Neutral in Hybrid Image Display systems," Eastman Kodak Research Laboratories, May.

M.E. Gorzynski and R. S. Berns, "Characterizing the Total Uncertainty of the Colorimetric Calibration of Color CRT's," Council for Optical Radiation Measurements Annual Meeting, Rochester, New York, May.

M.E. Gorzynski, "CRT Characterization at the Munsell Color Science Laboratory," United States National Committee of the International Commission on Illumination (CIE) Annual Meeting, Pennsylvania State University, Pennsylvania, October.

R.S. Berns and M.D. Fairchild, "A Real-Time Example of a Chroma Compression Visual Experiment," CIS Industrial Associates fall meeting, October.

M. Stokes, "Color tolerancing of pictorial images," CIS Industrial Associates Fall Meeting, October.

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.

A typical schedule of classes is the following:

	Fall	Winter	Spring
YEAR 1	PIMC 700 Vision and Psychophysics	PIMC 701 Applied Colorimetry	PIMC 803 Color Modeling
			PIMC 802 Optical Radiation Measurements
YEAR 2	PIMC 702 Theory of Color Measurement	PIMC 801 Color Science Seminar	
	PIMC 890 Research and Thesis	PIMC 890 Research and Thesis	PIMC 890 Research and Thesis

Short Courses

This last year, our short course entitled *COLORIMETRY: An Intensive Short Course for Scientists and Engineers* was again a success; the June course filled and we repeated the course during September. This was a three day course 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. Several changes were implemented for the 1990 course. First, a new 250 page coursebook was prepared using desktop publishing software. The entire faculty and staff contributed original artwork and new figures and tables. Munsell hue and chroma contours were drawn in xy, u'v', u*v*, and a*b* color spaces for values 3, 5, and and 7. These plots were invaluable in teaching the development of approximately uniform color spaces. Another change was the use of the Center for Imaging Science's new auditorium, which contains a Barco projection system. Color measuring systems were interfaced with this display and we could easily demonstrate the proper use of spectrophotometers and differences in the various manufacturers' software. We also conducted a color difference experiment where color difference pairs were displayed using the projection system. The experiment was great fun and showed participants from non-imaging industries the potential of imaging science in simulating color stimuli. Course participants were split evenly between materials applications and imaging. The date for next year's course has been set for June 11-13, 1991.

Our newest industrial Course, *Principles of Color Reproduction: An Intensive Short Course* taught by Dr. R.W.G. Hunt was again held in October. This year, the course was expanded to three days to include more fundamentals on color perception. Participants were mainly from the photography, graphic arts and electronic imaging industries. 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.

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 at Polaroid Corporation, March, 1990. (1 day)

2. *Colorimetry for Electronic Imaging*, presented at IBM Watson Research Center, New York, March, 1990. (2 day)

3. *Colorimetry for Electronic Imaging*, presented at IBM, Lexington Kentucky, May, 1990. (2 day)

4. *Colorimetry for Electronic Imaging*, presented at SPSE Annual Conference, Rochester, New York, May, 1990. (1 day)

5. *Color Reproduction Principles for Graphic Systems: Colorimetry Section*, presented by Imcotek, Inc., Boston, Massachusetts, June, 1990. (1 day)

6. *Colorimetry: Principles and Applications*, presented at 3M, St. Paul, Minnesota, June and November 1990. (2 1/2 days)

7. *Colorimetry for Electronic Imaging*, presented as part of Principles of Imaging Science, RIT, July, 1990. (1 day)

8. *Vision and Psychophysics* , presented as part of Principles of Imaging Science, RIT, July, 1990. (1 day)

9. *Colorimetry for Electronic Imaging*, presented as part of Imaging Science and Technology at Eastman Kodak Company, Rochester, New York, December, 1990. (1 day)

Industrial Liaison

Site Visits to Rochester Institute of Technology

Representatives of the following companies visited to tour facilities and discuss color-related issues during 1990:

Dupont Imaging, University of Rochester Radiology Department, University of Rochester Endoscopy Department, Hewlett Packard Corvallis, Sun Microsystems, BASF Pigmented Fibers Division, Toyo Ink Mfg. Co. Ltd., David Sarnoff Research Center, Eastman Kodak Company, Xerox Corporation, Milton Roy, Labsphere, NASA, 3M Company, BAM, Macbeth, Gretag, Minolta, X-Rite, and Konica.

Site Visits to Industry

Dr. Berns visited the following companies during 1990:

Optronics Laboratories, Inc., Orlando, Florida
Hewlett Packard Research Laboratories, Palo Alto, California
Tektronix, Beaverton, Oregon
DX Imaging, Lionville, Pennsylvania
R.R. Donnelley Lisle, Illinois
Xerox Corporation, Webster, New York
Eastman Kodak Company, Rochester, New York

Dr. Fairchild visited the following laboratories:

MIT Media Laboratory, Boston, Massachusetts
RPI Lighting Research Center, Troy, New York

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*, Amy North, December, 1990.

Past Publications

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

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.

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).

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).

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.

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.

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 is a new 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 a major research interest of The Center for Imaging Science, and the Munsell Color Science Laboratory established at RIT in 1983 is located within it. 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. Two other laboratories within the center for imaging science are involved in color science research. They are the Electric Imaging Laboratory founded by Xerox Corporation and the Electronic Printing Laboratory founded by Konica Corporation. 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

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

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

Cosar Pressmate I Densitometer
- Hand held, Status T, reflectance
- *Donation by Cosar Corp.*

Cosar 75 CompuPlus Densitometer
- Status A and Status M, reflectance head attachment
- *Donation by Cosar Corp.*

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

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

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

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 Labscan SpectroColorimetrer
400-700nm, 0/45, interference-wedge monochromator
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 range, d/0, 76 diode-array detector
Donation by Hunter Associates Laboratory

IBM Model 9420 Spectrophotometer
190-900nm, analytical, integrating sphere attachment
Donation by IBM

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

MCSL Goniospectrophotometer
Total control of 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, double beam, grating monochromator, PMT detector
Donation by MiltonRoy APD

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

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

Optronic 746-D Spectrophotometer
280-2500nm, 0/d, 3 grating monochromator

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

BYK-Gardner Glossgard II
20, 60, 85 degree units
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 grating monochromator, 32 diode array detector,
color matching software
Donation by BYK-Gardner

Photodyne 99XL Densitometer
Portable, fiber optic, transmission or 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 TV Color Analyzer TV-2160 Colorimeter
4 filter, designed to measure CRT, individual phosphor measurement, 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 Spectra Scan Spectroradiometer
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

ACS Datacolor VCS-10
Maxwell disk colorimeter
Donation by ACS Datacolor

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

Breneman Visual Colorimeter
Chromatic adaptation apparatus
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

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 (2)
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
IBM PC-AT host computer
Number 9, 512x512x32, RS-170, RGB display controller

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

Nagel Anomaloscope
Protan and deuteran testing

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

OSA Uniform Color Scales
Color order system

Color Display and Reproduction

Barco "Calibrator" Color Video Monitor
19V, black dot mask, DAF inline gun, 48-66 Khz H, 40-120 Hz V
Donation by Barco Industries

Bogen TC-1 Copy Stand
With 4 quartz-tungsten-halogen lamps

Color Image Input/Output Computer System
Sun Microsystems 3/260HM host computer
Sun Microsystems TAAC-1 Application Accelerator, 1024x2048x32
Sun Monochrome Monitor 19V, 1600x1280
National Instruments GPIB Bus
TAAC I donated by Sun Microsystems

HP 9000/375TSRX Research Computer System
HP 9000/375 host computer
HP 98731 graphics accelerator, 1024x2048x24
HP 98550 graphics processor, 1280x1024x8
Donation by Hewlett-Packard

HP 98745A Color Video Monitor
Sony Trinitron, 19V, 66Hz
Donation by Hewlett-Packard

HP 98789 Color Video Monitor
Sony Trinitron, 16V, 66Hz
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, RGB digital color photographic printer
On loan from Konica Corporation

Matrix ProColor Film Recoder
35mm digital film recorder

Pixar II Research Computer System
Sun Microsystems 3/160HM, Monochrome, 19V, 1152x900
Pixar II Image Computer 2M Pixels x 48, 12MB

Sony GDM-1950 Color Video Monitor
16V, Trinitron CRT, 48/63 Khz H, 60 Hz V

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

Student Color Modeling Computer System
IBM PC AT host computer
Number 9 Revolution 512x512x32, RS-170, RGB display controller
Chorus PC1200 RS-170, RGB video image capture board
Partial funding for display controller by Xerox Corporation

Tektronix 650HR-C Color Video Monitor
13V, Trinitron CRT, 6 MHz bandwidth
Donation by Tektronix

Tektronix 690SR Color Video Monitor
19V, dot mask, delta gun, 15-17 KHz H, 45-65 Hz V
Donation by Eastman Kodak Co.

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

For More Information

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