RICHARD S. HUNTER PROFESSORSHIP

MUNSELL COLOR SCIENCE LABORATORY

ANNUAL REPORT 1988

Rochester Institute of Technology

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Rochester, New York 14623-0887

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Report of the Richard S. Hunter Professor

Overview

This last calender year has been a very exciting one. Many of the research projects outlined in previous reports are fully under way. We have hired two full-time staff members, Ms. Lisa Reniff, our first graduate in the color science MS program and Ms. Barbara Capierseo. Welcome Barb and Lisa! We have had four applicants to our color science MS program for matriculation Fall, 1989. The Franc Grum Memorial Scholarship was inaugurated in November. Many of Franc's friends and colleagues attended. I know the excellent turnout meant so much to the Grum family. Following the inauguration, the Munsell Color Science Laboratory Advisory Board convened for the first time since 1984. They provided important input in terms of academic coursework, industrial seminars, and our standardization program. I was particularly pleased that Richard and Elizabeth Hunter could join us for both events.

During the year we had visitors from as close as the University of Rochester and as far away as Japan. We received a variety of equipment donations and unrestricted grants to augment our growing program. These recent donations have already contributed to current research and teaching. Additionally, Mrs. Elizabeth Hunter continues to support the activities of the Hunter Professorship with substantial personal monetary contributions. She has done so since the chair's inception and her support has enabled me to contribute to the color community through my attendance at technical conferences and technical committee work, often abroad.

It is worth noting that the Richard S. Hunter Professorship and the Munsell Color Science Laboratory were both established in the Fall of 1983. Thus this marks the 5 year point in formalized color science research and education at RIT. It seems appropriate to "catch my breath" and review my long term objectives for the next years. These long-term objectives can be divided into four parts: Education, Optical Radiation Measurements, Appearance Measurements, and Recruiting and Public Relations.

Education

My primary objective continues in the development of a strong educational program in color science. This includes industrial education as well as academics. Many new technologies such as pre-press proofing systems,

non-impact printers, and electronic publishing devices require the application of colorimetry to standardize the color of their products in order to eliminate device-dependent specifications. This practice of device-dependent specification is analogous to specifying the color of various parts of an automotive interior by the concentrations of colorants for each part required to achieve a certain appearance. Students, scientists, and engineers working in imaging science must be educated in colorimetry. Accordingly, I am developing seminars aimed at these audiences. Academic coursework also includes topics on the application of colorimetry to imaging. It is critical that color scientists broaden their influence into new technologies used to create and manipulate color. Traditional modalities such as textiles, coatings, and polymers are, as always, still given careful attention.

Another topical area is the application of colorimetry to quality assurance. Many users of color measuring instrumentation do not have an adequate understanding of statistical quality control. Furthermore, they are having difficulties applying univariate statistics to color which by definition is multivariate. I am beginning to restructure our courses along with Mr. Mark Fairchild to include more multivariate statistics and to stress quality control applications. I will be initiating a feasibility study to determine whether there is a need and a market for an industrial seminar aimed at the application of colorimetry to quality assurance.

Sadly, it is clear that students do not focus on communication skills as much as technical skills. I have found writing and speaking skills deficient in most of our students. Accordingly, one of our graduate color courses will become a seminar course where the students will be required to research a topic and give several hour seminars. We will also require our color science students to make one non-student technical oral presentation before graduation. With time, we hope to improve our students' communication skills.

Optical Radiation Measurements

My second objective is to maintain the Munsell Color Science Laboratory's capability to provide calibration and measurement services in optical radiation metrology traceable to the National Institute of Standards and Technology (formerly NBS). The precision and accuracy of our measurements should not exceed the total uncertainty of NIST. The following lists the hierarchy of developing Laboratory capabilities:

Primary transfer capabilities in visible reflectance spectroscopy: 45/0

Primary transfer capabilities in visible reflectance spectroscopy: integrating sphere

Goniospectrophotometric measurements for visible reflectance and transmittance

Spectroradiometric and colorimetric calibration of self-luminous displays

Research and development has been initiated in all these areas. Maintaining laboratory capabilities and facilities will become the responsibility of Ms. Reniff. In addition to developing limited calibration services, it is crucial we maintain our equipment and establish long-term in-house expertise in operating the equipment with a minimum of measurement uncertainty. One limitation in using students to perform some of these functions is the manpower inefficiency due to retraining and loss of expertise. I anticipate that Ms. Reniff will provide the continuity necessary to keep the Laboratory operating smoothly.

Appearance Measurements

It is clear that many of the unsolved problems in color science can be grouped into problems of appearance. For example: instrument correlation to visual assessment for materials with different gloss, brightness vs. lightness, chromatic adaptation for complex scenes, and soft copy to hard copy reproduction. My research focus will stress solving engineering problems resulting from a lack of understanding with respect to specifying appearance. Two pieces of apparatus have been designed and implemented to study appearance. The first is a colorimetrically calibrated image processor. This device offers extreme flexibility to address problems of color reproduction, absolute color appearance specifications, chromatic adaptation, and gloss. The first area I anticipate studying will address determining an observer's state of chromatic adaptation in soft-copy viewing environments.

The second device is a visual colorimeter capable of measuring color matching functions with normal eye movement and with complex scene surrounds. Often poor correlation to colorimetric specification results from a real observer having very different color matching functions to either CIE standard observer. This instrument will greatly enhance our educational efforts and research capabilities.

It should be stated that the study of appearance is closely linked to having excellent capabilities in optical radiation measurements. Ultimately, we estimate an observer's perception by a combination of physical measurement and mathematical modeling. We do not have control over the variability of observer responses except by increasing the number of observations and careful experimental design. We do have control of measurement uncertainty. Therefore, it is critical that our physical measurements are accomplished with a minimum of uncertainty.

Recruiting and Public Relations

In order to successfully implement the above objectives, we need students, faculty, and industry support. Recruiting and public relations are responsibilities that directly impact our future success.

My recruiting efforts have been limited to the normal RIT channels and exposure through my visibility while attending conferences, presenting seminars, and publications. When we are located in the new Center for Imaging Science building, I will initiate extensive recruiting efforts. During August, a brochure describing the MS degree in color science was prepared to aid in future recruiting efforts. With the increase in graduate applicants, it seems likely that the brochure is having a positive effect.

Rochester Institute of Technology is quickly becoming a center for color science due to the Richard S. Hunter Professorship, the Munsell Color Science Laboratory, and the Graphic Arts Division of the RIT Research Corporation. As the Hunter Professor, it is my responsibility to advance the state of the art in color science, appearance, and technology through scholarly activities, education, and developing liaison with industry. I have increased my involvement in national and international color-related organizations, increased my seminar activities, and widened the breadth of my research activities. My liaison with industry has been extensive with local industry, through seminars, and consulting with the RIT Research Corporation. Time permitting, I hope to visit more industrial sites on a national scale.

Other activities I have volunteered for that provide public relations to RIT are the organization of two technical conferences. I am co-chair of the ISCC Williamsburg conference on color discrimination psychophysics in 1989 and co-chair of the CORM 1990 annual meeting to be held at RIT in the New Center for Imaging Science building.

Conclusions

My accomplishments as the Richard S. Hunter Professor in Color Science, Appearance, and Technology would not have been possible without the support of my students, Mr. Mark Fairchild, Dr. Rodney Shaw, Dr. Thomas Plough, the Munsell Color Science Laboratory Advisory Board, Mr. Richard Hunter, Mrs. Elizabeth Hunter, our generous donors, and the color science community. In particular, Mrs. Hunter has generously given $10,000 per year since the inception of the Professorship to support the activities of the Hunter Professor. In the coming year, I will strive to successfully lead the RIT community in applied research and education in color science, appearance, and technology. I will continue to broaden our activities and influence research and development in modalities requiring a quantitative specification of appearance.

Respectfully submitted,

Roy Berns

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

January 19, 1989

Staff

Two faculty within the Center for Imaging Science are engaged in color science education and research: Dr. Roy S. Berns and Mr. Mark Fairchild. Dr. Berns is the Richard S. Hunter Professor the director of the Munsell Color Science Laboratory. Mr. Fairchild is responsible for teaching undergraduate color courses in the imaging science BS program and graduate courses in the MS program in color science. Mr. Fairchild is directing two research projects: the determination of color matching functions using a laser colorimeter and mathematical modeling of the goniospectrophotometric properties of white diffuse primary transfer standards.

During May, Ms. Barbara Capierseo was hired as a Staff Assistant to the Richard S. Hunter Professorship. Her responsibilities include invoicing, short course and seminar organization, and secretarial support.

During November, Ms. Lisa Reniff was hired as an Associate Scientist. Her current responsibilities are to maintain calibration services in optical radiation measurements and laboratory facilities. She will also be involved in research activities.

The following students are working hourly or as research assistants under the direction of either Dr. Berns or Mr. Fairchild:

Ms. Amy North
Senior, Imaging Science

Mr. Seth Ansell
Senior, Imaging Science

Mr. Jason Peterson
Graduate, Imaging Science

Mr. Mark Gorzynski
Grum Scholar
Graduate, Imaging Science

Mr. Mitch Rosen
Graduate, Imaging Science

Mr. Yan Liu
Graduate, Color Science

Facilities

The Munsell Color Science Laboratory is unusually well equipped housing most commercial devices used to characterize the optical properties of materials and light sources, and the visual system. Our current list of equipment is shown below.

Optical Properties of Materials

Applied Color Systems Spectro-Sensor II Spectrophotometer
400-700 nm, d/0, single beam, interference wedge,
Chroma-Calc color matching software for paints, textiles, and inks
Donation by Applied Color Systems and purchase

Beckman DK2A Spectrophotometer
185-3500nm, 0/d, analog, double beam, prism monochromator

Cary 17D Spectrophotometer
186-2650 nm range, analog and digital
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 Milton Roy APD

Diano/Hardy Recording Spectrophotometer
380-700 nm range, 0/d, analog, double-beam

General Electric Recording Spectrophotometer
380-700nm, 0/d, analog, double-beam, tristimulus integrator

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 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 Spectrophotometer
400-700nm range, 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

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

Macbeth 1500 Spectrophotometer
400-700nm, d/0, 16 diode array detector
Donation by Macbeth

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

MCSL Goniospectrophotometer
total control of illumination and viewing angles
Partially donated by Eastman Kodak Co. and funded by New York State Center for Advanced Technology

Milton Roy Color Scan Spectrophotometer
350-780nm, d/0, double beam, grating monochromator
Donation by Milton Roy APD

Milton Roy Color Scan/45 Spectrophotometer
350-780nm, 45/0, double beam, grating monochromator
Donation by Milton Roy APD

Minolta Chroma Meter I Colorimeter
hand held, d/0, D65, C
Donation by Minolta Corp.

Minolta Chroma Meter II Colorimeter
hand held, 45/0, D65, C
Donation by Minolta Corp.

Optronic Spectrophotometer
280-2500nm, 0/d, 3 grating monochromator
Funded by New York State Center for Advanced Technology

Pacific Scientific Colorgard System 1000 Colorimeter
0/45
Donation by Pacific Scientific

Pacific Scientific Glossgard II
20, 60, 85 degree units
Donation by Pacific Scientific

Pacific Scientific Spectrogard Spectrophotometer
d/0, interference wedge monochromator, color matching software
Donation by Pacific Scientific

Pacific Scientific The Color Machine Spectrophotometer
400-700nm, 45/0. grating and 32 diode array detector, color matching software
Donation by Pacific Scientific

Radiometry

LMT C1200 Colorimeter
17 filtered detectors, 2^{o} obs.
Donation by LMT

Minolta Chroma Meter II Incident Colorimeter
Hand held, 2^{o} obs.
Donation by Minolta Corp.

Minolta TV Color Analyzer TV-2160 Colorimeter
4 filter, designed to measure CRT, individual phosphor measurement, 2^{o} 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
Donation by Photo Research

Photo Research Spectra Spotmeter
radiometer/photometer

Schoeffel Monochromator (2)

Tracor Northern DARSS Spectroradiometer
240-870 nm range, 512 diode-array
Funded by New York State Center for Advanced Technology

Visual Instruments

Breneman Visual Colorimeter
chromatic adaptation apparatus
Donation by Eastman Kodak Co.

Japan Color Research Institute Chroma Cosmos 5000 (2)
Munsell based color order system

Dianolite Viewing Booth
3 booths, daylight tungsten and UV lamps
Donation by Milton Roy APD

D & H Color Rule (3)
Metameric slide rule, evaluation of obs. and ill. variability

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

ISCC Color Aptitude Test
Color discrimination and aptitude test

Isochromatic Plate Color Blindness Charts (many)
Ishihara, Dvorine, American Optical Co.

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

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

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

MCSL Laser Visual Colorimeter
laser primaries, measurement of color matching functions
Funded by New York State Center for Advanced Technology

Mitsubishi C3919N Color Monitors
3 monitors, studio grade
Donation by Macbeth

Munsell Book of Color
glossy and matte editions,
Donation by Munsell Color Co.

Nagel Anomaloscope
testing of protan and deuteran color vision defects
Donation by Eastman Kodak Co.

Tektronix 650HR-C Color Monitor
13", trinitron CRT
Donation by Tektronix

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

OSA Uniform Color Scales
Color order system

Donations

The 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 is particularly appreciated. Having state-of-the-art instrumentation makes our industrial seminars and our academic coursework very effective. Students from both programs gain extensive familiarity with them enhancing their current and future career potentials. From a research perspective, we recognize that colorimetry as a tool for estimating color perception is only effective when measurements are accurate and reliable. In our opinion, accurate color measurement is the foundation of all our research efforts.

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

Unrestricted research grants and gifts

PPG Foundation.....$5,000
Eastman Kodak $5,000
MCCA $3,160
Mobay Corporation.....$2,000

Devices

Donor	Device	Value
Macbeth	Computers, monitors, strip chart rec.	$10,000 (estimated)
Applied Color Systems	Chroma-calc software	$25,000
LMT	C1200 colorimeter	$18,000

Munsell Color Science Laboratory Advisory Board

In 1984, an advisory board to the Munsell Color Science Laboratory was established to provide input to the Laboratory director relative to the aims and purposes of the Munsell Foundation. As stated in its bylaws, the aims and purposes are

"...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."

On November 3, the advisory board met on the RIT campus. They provided input relative to our academic courses, industrial seminars, and calibration services. Many of their suggestions are reflected in the objectives stated in the above Report of the Richard S. Hunter Professor. The current members of the Advisory Board are as follows:

Dr. David H. Alman
E.I. du Pont de Nemours & Co.
P.O. Box 2802
Troy, NY 48007

Mr. Leroy DeMarsh
Eastman Kodak Company
Rochester, NY 14650

Dr. Henry Hemmendinger
438 Wendover Drive
Princeton, NJ 08540

Mr. Norbert Johnson
3M
3M Center 582-1-15
St. Paul, MN 55144-1000

Mr. Peter Engeldrum
Imcotek, Inc.
P.O. Box 66
Bloomfield, CT 06002-0066

Dr. Fred W. Billmeyer, Jr.
2121 Union Street
Schenectady, NY 12309

Mr. Richard S. Hunter
1703 Briar Ridge Road
McLean, VA 22101

Dr. Peter Kaiser
York University
Dept. of Psychology
4700 Keele Street
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Canada

Mr. Rolf G. Kuehni
Mobay Chemical Corporation
Dyes and Pigments Division
P.O. Drawer 2855
Rock Hill, SC 29730

Mr. Calvin S. McCamy
Macbeth
Drawer 950
Newburgh, NY 12550

Dr. Klaus D. Mielenz
National Bureau of Standards
Bldg. 220 B-306
Gaithersburg, MD 20899

Dr. Yoshinobu Nayatani
Osaka Electro-Communication Univ.
18-8 Hatsu-uho
Neyagawa, Osaka 572
Japan

Mr. Milton Pearson
RIT Research Corporation
75 Highpower Road
Rochester, NY 14623-3435

Mr. Ralph Stanziola
410 Clover Street
Neshanic Station, NJ 08853

Mrs. Joy Turner Luke
Studio 231
Box 18 Route 1
Sperryville, VA 22740

Mr. Cornelius J. McCarthy
Milton Roy Company APD
820 Linden Avenue
Rochester, NY 14625

Dr. V.S. Mihajlov
Xerox Corporation
Xerox Square
W1477-58A
Rochester, NY 14644

Dr. Noboru Ohta
Fuji Photo Film Co., Ltd.
210 Nakanuma, Minami-ashigara
Kanagawa-ken 250-01
Japan

Dr. Alan R. Robertson
National Research Council
Division of Physics
Ottawa, Ontario KIA OR6
Canada

Research and Development

The students and faculty of the Munsell Color Science Laboratory are involved in a variety of research programs. These programs fall within the framework of the Laboratory's long-standing objectives of performing applied research and development applicable to current industrial needs. Periodically, we initiate small research projects which are fundamental in nature; these projects are primarily educational for our students and faculty. Often, these projects lead to further applied research. The following lists the current research and development projects, staff involvement, and sources of funding.

Determination of color-matching functions using a laser primary visual colorimeter

Research director: Mr. Mark Fairchild
Staff member: Ms. Amy North
Funding: New York State Center for Advanced Technology

Colorimetric calibration of raster-scan CRT displays

Research director: Dr. Roy Berns
Staff members: Mr. Mark Gorzynski, Mr. Seth Ansell
Funding: Richard S. Hunter Professorship, Munsell Color Science Lab.

Goniospectrophotometric properties of white diffuse primary transfer standards

Research director: Mr. Mark Fairchild
Co-researcher: Dr. Roy Berns
Staff members: Ms. Lisa Reniff, Mr. Jason Peterson
Funding: Department of Energy

Degree of chromatic adaptation to spatially complex backgrounds

Ph.D. Thesis: Mr. Mark Fairchild
Advisory Committee: Dr. Peter Lennie (University of Rochester),
Dr. Roy Berns
Dr. Mary Hayhoe (University of Rochester)
Funding: Department of Energy, Center for Imaging Science Industrial Associates Program, Munsell Color Science Laboratory

Color Discrimination Psychophysics

Research director: Dr. Roy Berns
Staff members: Ms. Lisa Reniff, Mr. Mitch Rosen, Mr. Yan Liu
Funding: E.I. duPont de Nemours Co.

Effect of ambient illumination in perceived white balance in soft copy displays

Research director: Dr. Roy Berns
Staff member: Mr. Mark Gorzynski
Funding: Richard S. Hunter Professorship, Munsell Color Science Laboratory

Dependence of crossover wavelengths of metameric pairs on colorant absorption properties

Research director: Dr. Roy Berns
Co-researcher: Mr. Rolf Kuehni
Funding: Richard S. Hunter Professorship, Mobay Corp.

Calibration capabilities in 45/0 spectral reflectance factor measurements

Research director: Dr. Roy Berns
Staff member: Ms. Lisa Reniff
Funding: Munsell Color Science Laboratory

Artificial Neural Networks for Color Appearance Description

Research director: Mr. Mark Fairchild
Co-researcher: Dr. Mary Hayhoe
Funding: Munsell Color Science Laboratory, Center for Imaging Science Industrial Associates Program

Industrial Liaison

Short Courses & Seminars

In 1988, the Munsell Color Science Laboratory continued to offer its short course entitled; *COLORIMETRY: An Intensive Short Course for Scientists and Engineers.* This is a three-and-a-half day course designed to teach the effective application of colorimetry to persons involved in coatings, textiles, polymers, reprographics, and electronic imaging. It is particularly useful for personnel currently using or contemplating using commercial color measuring instrumentation for quality control.

The course follows course notes prepared in the Munsell Laboratory as well as the textbook *Principles of Color Technology, 2nd Ed.* by Billmeyer and Saltzman. The objectives of the course are to: identify the important variables in visually evaluating color and color differences; derive in detail the CIE system of colorimetry; study the accurate calibration and correct use of current color measuring instruments; identify proper measuring technique for given materials; develop methods to apply colorimetry to quality control; and develop the principles of computer colorant formulation.

These courses continued to be very successful in the past year. Two courses were offered in June. 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 and on site. Below is a list of these seminars from the past year.

1. *Colorimetry for Electronic Imaging Devices* presented at SPIE Conference, January, 1988 Los Angeles, CA (1 day)

2. *Principles of Imaging Science:* Colorimetry Section, organized by Eastman Kodak Company Training Department, March, 1988 (1 day)

3. *Color Reproduction Principles for Graphic Systems:* Colorimetry Section, presented by Imcotek, Inc., May, 1988 at Boston, MA (1 day)

4., 5. *COLORIMETRY: An Intensive Short Course for Scientists and Engineers,* presented twice, June, 1988 at RIT (3 1/2 days)

6. *Colorimetry for Electronic Imaging Devices* presented at Eastman Kodak Company, Apparatus Division, July, 1988 (2 day)

7. *Colorimetry for Electronic Imaging Devices* presented at RIT, July, 1988 (1 day)

8., 9. *COLORIMETRY: An Intensive Short Course for Scientists and Engineers,* presented at 3M in St Paul, MN twice, August, 1988 (2 1/2 days)

10.,11. *Principles of Imaging Science:* Colorimetry Section, organized by Eastman Kodak Company Training Department, presented twice, October, 1988 (1 day)

Site Visits to Rochester Institute of Technology

Representatives of the following companies visited the Munsell Color Science Laboratory during 1988:

Konica , Olivetti, Polaroid, PSI, Eastman Kodak, Intersystems Graphics, Dimension Technologies, LMT, Barco Industries, Genigraphics, Dainippon Ink & Chemicals, Polychrome, Champion Textiles, Hunterlab, Macbeth, Welch-Allyn, 3M, Dupont, Mitsubishi Paper Mills, Nanometrics, Rank Cintel, Sharp, Videojet, Imaging and Sensing Technology., ACS, Sun Microsystems

Site Visits to Industry

Dr. Berns visited the following companies during 1988:

Eastman Kodak, Hunterlab, Dupont, 3M, Polaroid.

Mr. Fairchild visited the following companies during 1988:

Hewlett Packard, SRI International

Publications

The following is a list of the articles published by faculty and students of the Munsell Color Science Laboratory to date:

1985

Standards and Standardization in Optical Radiation Measurements, Grum, Pearson, and Scharpf, 1985 TAGA Proceedings.

Thermochromism of Ceramic Reference Tiles, Fairchild and Grum, **Applied Optics 24**, 3432(1985).

Metameric Mismatch Limits of Industrial Colorants, Berns, **Mondial Couleur 85**, proceedings of AIC, paper 40, 1985.

Spectrogoniophotometric Properties of Standard Reference Materials, Grum and Miller, **Mondial Couleur 85**, proceedings of AIC, paper 53, 1985.

1986

A FORTRAN Program for Predicting the Effects of Chromatic Adaptation on Color Appearance based on Current CIE Recommendations, Berns, **Color Res. Appl. 11** 82(1986).

1987

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

Illuminating Artwork: Consider the Illuminating Source, Berns and Grum, **Color Res. Appl. 12**, 63(1987).

Goniospectrophotometric Characteristics of Common Transfer Standards with respect to CIE Normal/45 Geometry, Grum, Fairchild, and Berns, proceedings ISCC Williamsburg, 43(1987).

Visual Determination of Color-Difference Vectors, Berns, Alman, and Snyder, proceedings 21st session of the CIE, Vol. I, 134(1987).

Goniospectrophotometric Characteristics of White Reflectance Standards with respect to the CIE Normal/45 Geometry, Grum, Fairchild, and Berns, proceedings 21st session of the CIE, Vol. I, 134(1987).

Analysis of Color in Electrophotographic Images, Burningham and Berns, proceedings SPSE 40th annual conference, 90(1987).

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

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

An Algorithm for the Optimization of Kubelka-Munk Absorption and Scattering Coefficients, McCarthy, Walowit, and Berns, **Color Res. Appl. 12**, 340(1987).

1988

The Colorimetric Calibration of a CRT Imaging System for Color Appearance Research, Motta and Berns, proceedings ISCC - SID joint meeting (1988).

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

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

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

Ganglion Cell Pathways for Rod Acuity, Fairchild and Lennie, proceedings of OSA Annual Meeting, 132(1988).

Empirical Modeling of Systematic Spectrophotometric Errors, Berns and Petersen, **Color Res. Appl. 13** 243(1988).

Spectrophotometric Color Matching Based on Two-Constant Kubelka-Munk Theory, McCarthy, Walowit, and Berns, **Color Res. Appl.13**, 358(1988).

The Quantification of Illuminant Metamerism for Four Coloration Systems vis Metameric Mismatch Gamuts, Berns, Fairchild, and Beering, in press **Color Res. Appl. 13**, 346(1988).

Evaluation of Color-Difference Equations Using a Visual Color Tolerance Dataset, Berns, Alman, Snyder, and Larsen, proceedings AATCC 1988 annual meeting.

1989

The following were accepted for publication or presentation as of January 1, 1989:

A Novel Method for the Determination of Color Matching Functions, Fairchild, in press **Color Res. Appl.**

Performance Testing of Color-Difference Metrics Using a Color Tolerance Dataset, Alman, Berns, Snyder, and Larsen, in press **Color Res. Appl.**

Dependence of Crossover Wavelengths of Metameric Pairs on Colorant Absorption Properties, Berns and Kuehni, AIC 1989 quadrennium, March.

A Principal Components Analysis of Diffuse Reflectance Standards, Fairchild, Peterson, and Berns, CORM 1989 Annual Meeting, May.

Color Community Service

Dr. Berns is involved in the following color-related technical organizations:

Inter-Society Color Council: member of the Board of Directors, Co-chairman in colorimetry and measurement interest group

Council for Optical Radiation Measurements (CORM): member of the Board of Directors and active in the array radiometry subcommittee

American Society for Testing and Materials (ASTM): member of E-12

Society for Imaging Science and Technology (SPSE): Councillor of Rochester chapter

International Commission on Illumination (CIE): member of TC 2-11 committee of gonioreflectometry of standard materials, TC 2-26 committee on measurement of color self-luminous displays, and TC 2-28 committee on methods of characterizing spectrophotometers