11-1-1997

A Study of effect of CRT gamma and white point on softcopy and hardcopy agreement

Shih-Lung Kuo

A Study of Effect of CRT Gamma and White Point on Softcopy and Hardcopy Agreement

by

Shih-Lung Kuo

A thesis submitted in partial fulfillment of the
requirement for the degree of Master of Science in the
School of Printing Management and Sciences in the College
of Imaging Arts and Sciences of the
Rochester Institute of Technology

November 1997

Thesis advisor: Professor Robert Y. Chung

School of Printing Management and Sciences
Rochester Institute of Technology
Rochester, New York

Certificate of Approval

Master's Thesis

This is to certify that the Master's Thesis of

Shih-lung Kuo
name of student

With a major in Printing Technology
has been approvaed by the thesis Committee as satisfactory for the thesis requirement for the Master of Science degree at the convocation of

November 1997
date

Thesis Committee

Robert Y. Chung
Thesis Advisor

Joseph L. Noga
Graduate Program Coordinator

C. Harold Goffin
Director or Designate

Title of thesis A Study of Effect of CRT Gamma and White Point on Softcopy and Hardcopy Agreement.

I, Shih-Lung Kuo, **Prefer to be contacted** each time a request for reproduction is made. I can reached at the following address: fred5697@ms15.hinet.net.

Date November, 1997.

Acknowledgment

Great thanks to Professor Robert Y. Chung for his encouragement on this topic and his support for all the hardware and software needed in this study.

Thanks to my research advisor Professor Richard A. Holub for his knowledgeable feedback and his patiently investigation on my research.

To the friends in RIT who accompany me these years.

To my parents.

Table of Contents

Chapter 1–Introduction..........1
Terminology..........2
  Gamma..........2
  Chromaticity..........6
  White Point..........6
  Color Management System..........8
  Device Profile..........8
  Matching Style..........8
  Ambient Light..........9
  CMS Procedure..........10
Statement of the Problem..........11
Contrast and Brightness Setting..........12
CRT Calibration..........12
  Gamma Calibration..........12
  White Point Calibration..........15
Summary..........17
Endnotes..........18
Chapter 2–Background Theory..........19
Mathematical Management of Color..........19
CIE System..........20

Color Space Transformation........23
Summary........25
Chapter 3–Review of Literature........26
Chapter 4–The Hypothesis........29
Statement of the Hypotheses........29
Chapter 5–Methodology........30
5.1. Delimitation of the Study........30
5.2 Experimental Design........31
5.2.1 Equipment and material........31
5.2.2 Preparation of device profiles........32
5.3 Part I Observer Experiment........32
5.4 Part II. Colorimetric Analysis........33
5.4.1 Preparation of Hardcopy Colorimetric Data........34
5.4.2 Preparation of Softcopy Colorimetric Data........34
5.4.3 Analyzation of Colorimetric Data........35
Chapter 6–The Results........36
The Influence of the CRT Profile........36
Further Analysis........38
The perception differences between different type of images........38
Inverse relationship between profile gamma and image gamma........39
The image reproduction with different profile white point........40
The agreement between colorimetric data and human perception........42
Chapter 7–Summary and Conclusion........43
Conclusions of the Hypotheses........44
Recommendation for Further Study........44

References...46

Appendix A: Contrast and Brightness Setting 50
Appendix B: The Calculation of Gamma..59
Appendix C: Data of Observer Experiment...63

List of Tables

Table-1. Gamma calibration of three CRT testing 14

Table-2. The intrinsic and calibrated chromaticity of the white point of three test monitors15

Table-3. Colorimetric data from Rainbow in CIE x, y, Y format.............................34

Table-4. Non-Triads samples and the statistics testing..38

Table-5. Comparison of colorimetric data and observer experiment..........................42

List of Figures

Figure-1. The slope of the straight-line section is called the gamma. 3
Figure-2. A CRT with a response of gamma 2.5 4
Figure-3. For CRT device, input is a voltage controlled by the video card and the output is the brightness produced by the phosphor. 5
Figure-4. Most imaging devices are non-linear. Notice how the deviation from the straight-line is most pronounced in the midtones 5
Figure-5. White point chromaticity 7
Figure-6. CMS procedure 10
Figure-7. ColorTron Calibrator control panel 13
Figure-8. The chromaticity diagram of white point calibration 16
Figure-9. The CMS in Photoshop 28
Figure-10. Test patches design 34
Figure-11. Three musicians non-triads samples under dark ambient light 37
Figure-12. Orchid non-triads samples under dark ambient light 37
Figure-13. Hardcopy gamma and CRT gamma 39
Figure-14. Relationship between profile gamma and image gamma 40
Figure-15. White point reproduction 41

Abstract

DTP (Desk Top Publishing) professionals rely on CRT displays to provide visual feedback to adjust or to proof color prior to hardcopy. Solutions are now appearing in the market to meet this need. But the proper CRT calibration is still not clear to the end users.

The objective of this work is to study the CRT setting in terms of gamma and white point; and to explore gamma and white point's effects on softcopy (CRT displayed image) and hardcopy (CMYK printed image) agreement. A number of CRT calibration experiments were performed. Two SCID (Standard Color Image Data) images were used in this study to test the agreement between a softcopy and a hardcopy image.

A number of color measurement devices and color management software packages were used in this study. Specifically, ColorTron was used in this study as the tool to calibrate the CRT. Adobe Photoshop, with the ColorSync 2.0 plug-in module was used in this study to implement the printer CMYK to CRT RGB transformation. ColorBlind was used in this study to generate printer and monitor profiles. CA-100 was used in this study as a colorimetric measurement device for data collection and image gamma analysis.

By means of observer experiment conducted under dark ambient light, it was found that the different CRT profiles do influence the color transformation between printer CMYK and CRT RGB; the system's default CRT profile (gamma=1.8, whit point=D50, out of 6 CRT profiles tested) cannot achieve the best match between CRT and hardcopy. The optimum CRT profile for the best match was not to be found because of the influence of the keyness of the image itself.

Chapter 1

Introduction

When color electronic prepress technology shifts to the desktop computer, the pursuit of WYSIWYG (What you see is what you get) from user's CRT (Cathode-Ray Tube) to output device continues. A successful implementation of WYSIWYG was evidenced in typeface when Adobe introduced the Postscript font. The solution for a color image WYSIWYG is just beginning.

Although many vendors introduced their proprietary CMS (Color Management System) solutions to the market as early as 1992, e.g., Efi Works and Agfa FotoTune 1.0, lack of an open interface made it costly and difficult to exchange color picture data with other users.

The open system CMS, introduced by Apple in 1993 as ColorSync 1.0, was not successful. ColorSync 2.0, introduced in 1995, was better than its predecessor in many ways, but probably its most important feature is the introduction of the ICC (International Color Consortium) device-profile format. The ICC format has been supported virtually by all vendors in the color management arena as well as by the most important operating-system vendors, including Apple and Microsoft. The emergence of ICC as a common cross-platform device-profile standard has provided the impetus for third-party vendors to produce custom profiling tools. Custom profiling means that user can create their own device profiles instead of using the generic profiles supplied by the hardware vendors.

This study is focused on softcopy (CRT image) to hardcopy (printer image) agreement under an ICC compliant CMS procedure. This makes the choice of monitor profiling hardware and software a major issue in this study.

At the end of 1995 Light Source introduced ColorTron II which supports the ColorSync 2.0 format. Because of its affordable price tag, custom CRT profiling became available for mass-market end users. ColorTron II was used in this study for CRT calibration.

Minolta CA-100 is a CRT color measurement device used by the television industry for quality control. This device was used in this study to verify the calibration capability of ColorTron II and provide CRT colorimetric data for analysis.

Terminology

This study involves technology in the fields of CRT, color science, desktop publishing, and color management. The key terms used in this study include: gamma, white point, device profile, and CMS procedure.

The terms gamma, chromaticity, white point, color management system, device profile, matching style, ambient light, and CMS procedure as used herein are explained as follows.

Gamma

The original definition of gamma comes from *D*-log *H* curves, or *characteristic curves*, used in the photography industry; such curves often have an approximately straight-line section in the middle with curved sections of lower gradient on either end, as shown in Figure-1. The low-density curved section is often referred to as the *toe*, and the

high-density curved section as the *shoulder*, of the curve. The slope, or the gradient of straight-line section is called the *gamma*[1]. The higher the gamma, the higher the picture contrast is in the highlight-to-middletone portion of a photographic image.

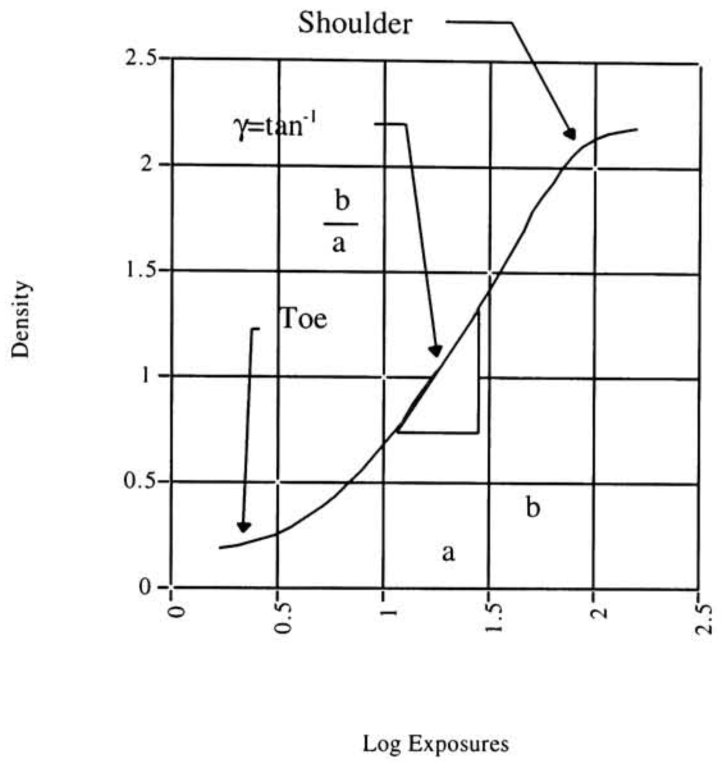
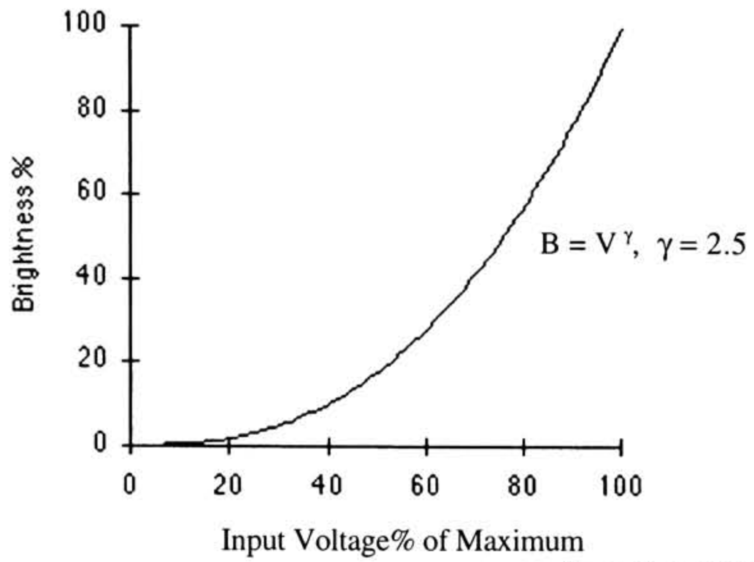


Figure-1. The slope of the straight-line section is called the *gamma.*

In the early days of the television industry it was discovered that a CRT does not produce a brightness that is proportional to the input voltage. Instead, the brightness produced by a CRT is proportional to the input voltage raised to a power. The raised power number is also called *gamma* by the television industry[2]. A CRT with a gamma of 2.5 has a response like Figure-2.



Source: Robert W. Berger. Online

Figure-2. A CRT with a response of gamma 2.5

In general, the gamma of a device is a number used to describe the tonal relationship between its input and its output. Although most commonly used to describe monitors, gamma is also applied to scanners, printers, or even images. Notice that the difference in CRT gamma , as shown in Figure-3 and Figure-4, is the gradation from highlight to midtone.

In this study, the term "gamma" will appear in several situations; hence, a separate definition of gamma in those situations is explained as follows:

CRT gamma (γ_{CRT}): The physical appearance relationship of CRT in terms of $Y_{CRT}=DC^{\gamma}$, where DC is CRT input digital counts and Y is the intensity measured from CRT surface.

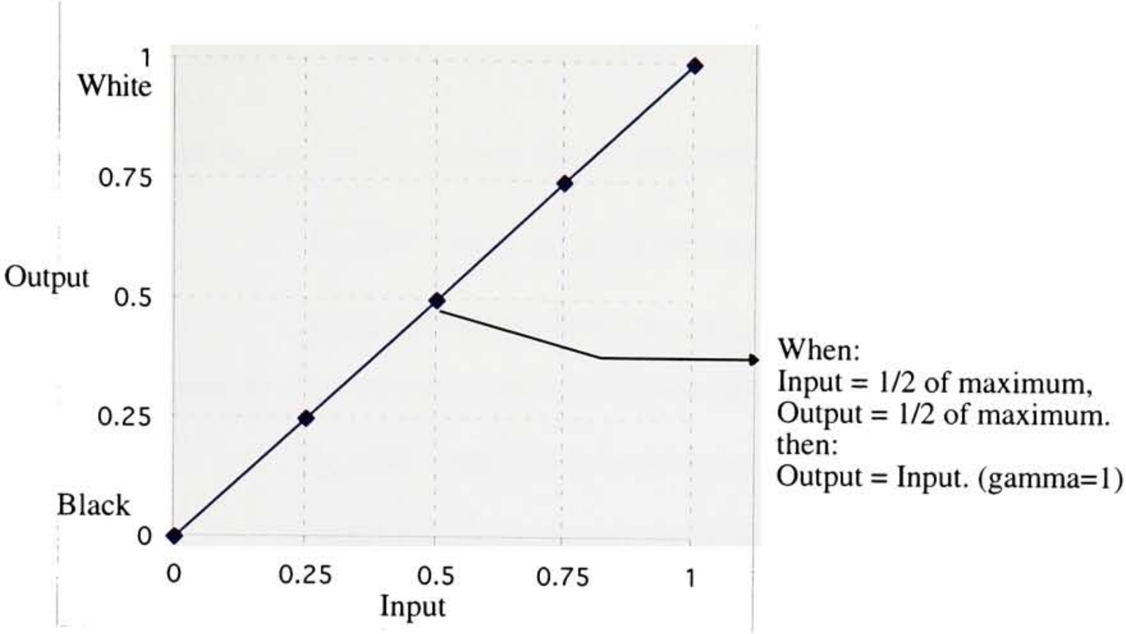


Figure-3. For CRT device, input is a voltage controlled by the video card and the output is the brightness produced by the phosphor.

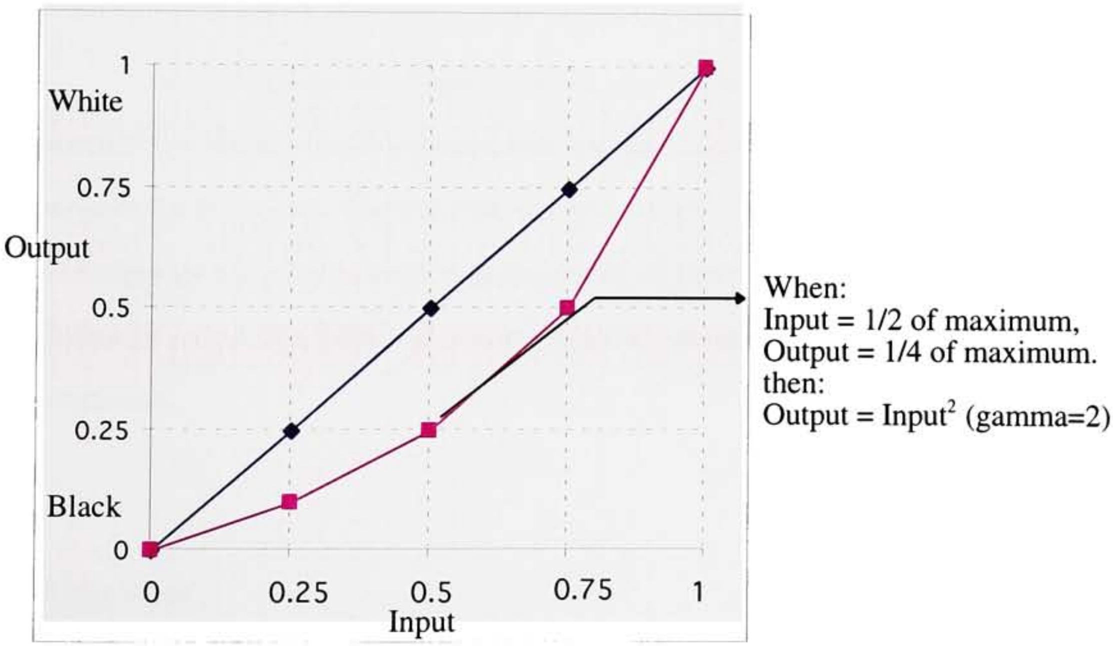


Figure-4. Most imaging devices are non-linear. Notice how the deviation from the straight-line is most pronounced in the midtones.

Profile gamma ($\gamma_{profile}$): A parameter declared on a monitor profile that influences the CRT RGB to CIE space conversion.

Print gamma (γ_{print}): The physical appearance relationship of the image on paper in terms of $Y_{ink}=DC^{\gamma}$, where DC is the CRT digital counts input and Y is the intensity measured from ink on paper.

Softcopy gamma : In a softproof process, the relationship of the image on CRT in terms of $Y_{CRT}=HT^{\gamma}$, where HT is the hardcopy tone value and Y is the intensity measured from surface of CRT of the softproof image.

Chromaticity

Color, independent of luminance. In other words, two colors that seem to be identical except for overall intensity, have the same chromaticity. In general, we can separate the perceptual effect of color into two components: chromaticity and luminance. Chromaticity is what we perceive as the strictly color-related component and is itself often (although not always) broken down into hue and saturation. Luminance is associated with brightness.

White Point

The chromaticity of a light source or other emissive object. The white point of an emissive object is expressed in one of two ways: by giving the white point's correlated

color temperature (5000K, 6500K) or its chromaticity coordinates ([0.345, 0.358], [0.312. 0,329] .) The intrinsic Mac CRT has a bluish white point (9300K)[3] compare to the Graphic Arts standard light source (5000K.) Refer to Figure-5 for their chromaticity coordinates.

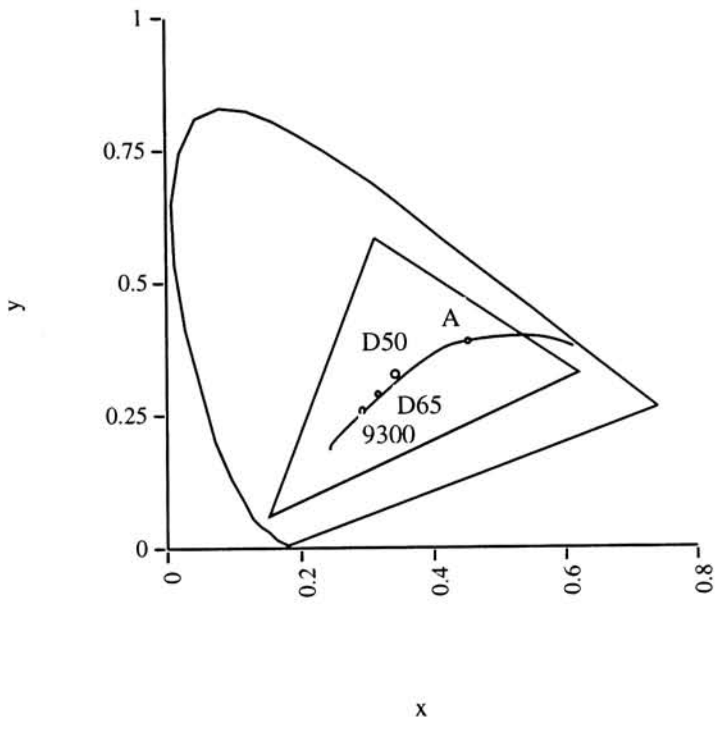


Figure-5. White point chromaticity

The term "white point" will appear in three situations in this study, and is further described as follow:

Illuminant white point:: The illuminant white point is the chromaticity of the light source when viewing the hard copy.

CRT white point: The CRT white point refers to the chromaticity of the CRT's highest output (the x, y reading of RGB digital count at 255, 255, 255). Since

the CRT is a self-illuminate display device, when viewing a CRT image, the white point of the CRT is the same as illuminant white point.

Profile white point: The profile white point is the parameter declared in the monitor profile that influences the transformation between CRT RGB and CIE space.

<u>Color Management System</u>

Abbreviated CMS, a set of software, and sometime hardware, as part of a computer system designed to handle automatically the conversion of colors from device-to-device according to a rendering intent. Each device is represented by a profile created by means of calibration or characterization determined with the use of the CMS software/hardware.

<u>Device Profile</u>

In a color management system, a file containing data representing the color reproduction characteristics of the device—producing what are known as printer profiles, monitor profiles, scanner profiles, or in general, a device profile. A profile is created by using either calibration, or characterization, or a combination of both methods.

<u>Matching Style</u>

Because of the differences among devices' color capability, different methods exist for applying color matching on an image. The matching style is usually selected according to the content of the image . See below.

Perceptual matching style: A matching style which gives the most pleasing reproduction given the capabilities of the devices involved. This is the most commonly used style, especially for reproduction of photographic images.

Colorimetric matching style: A matching style where colors are reproduced exactly the same as the eye can distinguish. This may result in clipping of certain colors which can not be reproduced on a device. Colorimetric matching can further be divided into relative colorimetric matching and absolute colorimetric matching, where relative matching accounts for the ability of the human eye to automatically adapt to the surround white (e.g., white of the paper the image is printed on), and absolute does not. Colorimetric matching is most commonly used for reproducing logo colors where the exactness of the color is important.

Saturation matching style:A matching style where the vividness of the image is best preserved. This style is mostly used for reproduction of graphs and pie charts.

This study tests only the perceptual match between CRT and hardcopy image.

Ambient Light

In this study, ambient light refers to the surround brightness around the CRT; the bright ambient decreases the CRT contrast by reflecting light into the CRT faceplate and de-saturates the CRT image. The CRT image under dim ambient light will reveal more shadow detail and greater saturation than the same image viewed under bright ambient light. All the experiments in this study are conducted under dark ambient light.

CMS Procedure

This study focuses on using a CRT to simulate CMYK data of hardcopy. The procedure to transform the CMYK data to RGB data and the observation scheme are summarized in Figure-6.

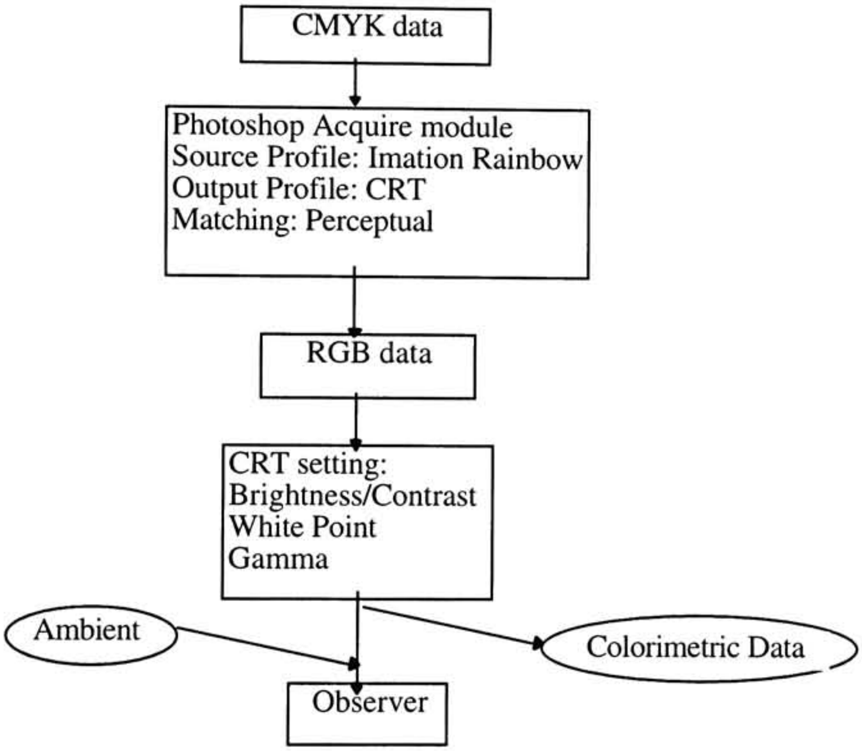


Figure-6. CMS procedure

The procedure starts with CMYK data. The reference is the CMYK data rendered in the form of a hardcopy image (in this study, the Imation Rainbow). The CMYK data is then transferred to RGB through the printer profile and the CRT profile under Photoshop ColorSync plug-in (Acquire) module. The perception of RGB data is influenced by the

CRT hardware setting, that is, brightness/contrast setting, white point setting, and gamma setting.

There are several factors which could affect the reproduction process and perception. This study tests only two CRT parameters (gamma and white point) and ambient conditions, and studies the effects in achieving an optimum match between CRT and hardcopy.

Statement of the Problem

The CMS algorithm governs the mapping of the device color to an independent color space (CIE space) and translates it to other image devices. From this basic conception, commercial CMS packages are available in the market for end users to deal with image reproduction on a desktop system. However, does the performance of these products fit into the user's need? Is there any method that we can use to adjust the outcome of the CMS software when their results are not to our expectation?

When using the CMS procedure, the proper use of the CRT calibration is still not clear to end users. For example, the ICC monitor profile does not include any ambient factor. In fact, ambient light does affect the perception of an image; some vendor's manuals use the CRT gamma setting as a factor for compensating for the dot gain of the hardcopy, but some literature explain that CRT gamma is used to compensate for the different viewing conditions from the CRT (dim) to hardcopy (bright).

In this study of CRT softcopy to CMYK hardcopy agreement, the main factors investigated are gamma and white point. How significant are these factors will affect the agreement? How close can we achieve an agreement through these factors?

Contrast and Brightness Setting

A preliminary test was conducted on the CRT hardware settings. The major issue of the test was the contrast and brightness settings. Two literature about contrast and brightness settings were reviewed and verified. One procedure starts the settings from contrast control[5] while the other one starts from brightness control[6]. This study will set the CRT starting with contrast control according to the ColorTron's user manual. See Appendix A for detail discussion of the contrast and brightness settings.

CRT Calibration

Gamma Calibration

Monitor calibration helps standardize the hardware aspect of the monitor display. Gamma calibration further adjusts the monitor display to simulate a reference condition. As explained in the ColorTron's manual, Macintosh CRTs are set to 1.8 gamma. This is because in the early days of desktop publishing on the Macintosh, a monitor gamma of 1.8 provided a first approximation of how images would appear when printed on a laser printer[3] (for compensation of about 20% of dot gain on a laser printer).

A similar explanation also found in Poynton's paper on gamma:

Standard offset printing involves a dot gain at 50% of about 24%, the results in a transfer function from RGB code to reflectance of print that closely resembles the voltage-to-light of CRT. Correction of dot gain is conceptually similar to gamma correction in CRT where the numerical value of the exponent is about 1.75.

CRT gamma only affects how the data is displayed, and it does not affect the hardcopy output of the data.

CRT calibration involves adjustments of the white point and the gamma of a CRT to known values. The ColorTron Calibrator is a combination of software and hardware which is capable of performing calibrations to generate a CRT profile. Refer to Figure-7 for the ColorTron Calibrator control panel.

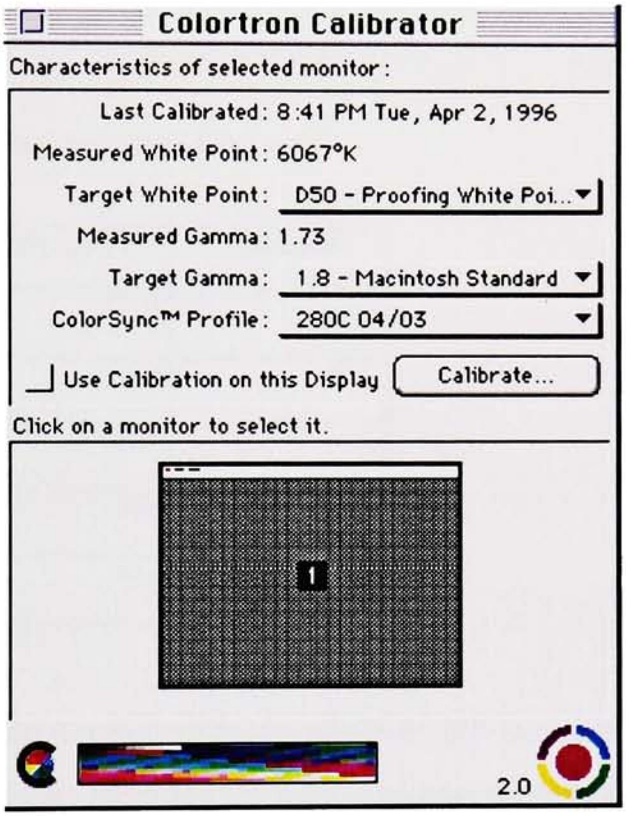


Figure-7. ColorTron Calibrator control panel

Refer to Figure-7, this study intends to calibrate CRT to D50 white point and gamma 1.8. The Minolta CA-100 is used in this study to verify the capability of the ColorTron Calibrator. The actual colorimetric information collect by CA-100 from CRT could provide the information of whether the ColorTron Calibrator is the instrument that is capable for this study. For a verification on calibrating a CRT to a target 1.8 gamma, here are the results of three monitors that were tested:

CRT-1: An Apple 14" multimedia monitor

CRT-2: Apple 16" MultiSync monitor

CRT-3: Another Apple 16" MultiSync monitor

Refer to Appendix B on how to calculate CRT gamma from colorimetric data. The gamma of the three CRTs before calibration and after calibration shows as Table 1.

Table-1 Gamma calibration of three CRT tests

CRT	Pre-calibration	Calibrated
1	1.362	1.809
2	1.601	1.863
3	1.642	1.912
Average	1.535	1.861
Range	0.28	0.103

The Mac system is supposed to have a built-in CRT gamma correction for 1.8. Table 1 shows that before calibration, there is a quite large deviation from 1.8. The deviation could result from brightness/contrast settings or the different specification of the different CRT maker. In this case, the two Apple 16" monitors are from same maker, same model; they have a close performance of 1.6 and 1.64 gamma. The other CRT with a gamma of 1.36 is from another maker and has a large deviation from 1.8. The information reveals that the specification on the vendor's manual does not represent the actual performance of the hardware.

After the calibration, the resulting gamma was 1.81, 1.86 and 1.91. It shows that the ColorTron Calibrator is capable of bringing back the intrinsic gamma to the target gamma of 1.8. But there is still a 0.1 deviation at the third CRT.

White Point Calibration

The white point of the CRT refers to the chromaticity of the CRT's highest output (the x, y reading of RGB digital count at 255, 255, 255). All RGB digital count display on CRT will appear different according to the white point . The same digital count will appear bluer under D93 (9300K) CRT then in D50 (5000K) CRT.

The intrinsic white of a CRT is 9300K. It is bluish compare to D50 (standard hardcopy viewing white). This study is designed to use D50 as standard light source. In order to bring the CRT's 9300K bluish white to D50 white, the intensity of the blue and green channel is reduced to achieve this purpose. A test mentioned in Appendix A–Contrast and Brightness setting, shows that a reduction of about 27% of the green intensity and 62% of the blue intensity are necessary to bring the bluish CRT to the D50 white.

Again, the Minolta CA-100 is used to verify the ColorTron Calibrator's capability of white point calibration. The following three monitors were tested for white point calibration aimed to D50 white with results shown in Table 2.

CRT-1: Apple 14" multimedia monitor.

CRT-2: Apple 13" standard RGB

CRT-3: Apple 16" MultiSync monitor

Table-2 The intrinsic and calibrated chromaticity of the white point of three test monitors

CRT	Pre-calibration		Calibrated	
	x	y	x	y
D-50	0.35	0.36	0.35	0.36
1	0.277	0.285	0.365	0.359
2	0.263	0.283	0.369	0.367
3	0.293	0.302	0.359	0.36

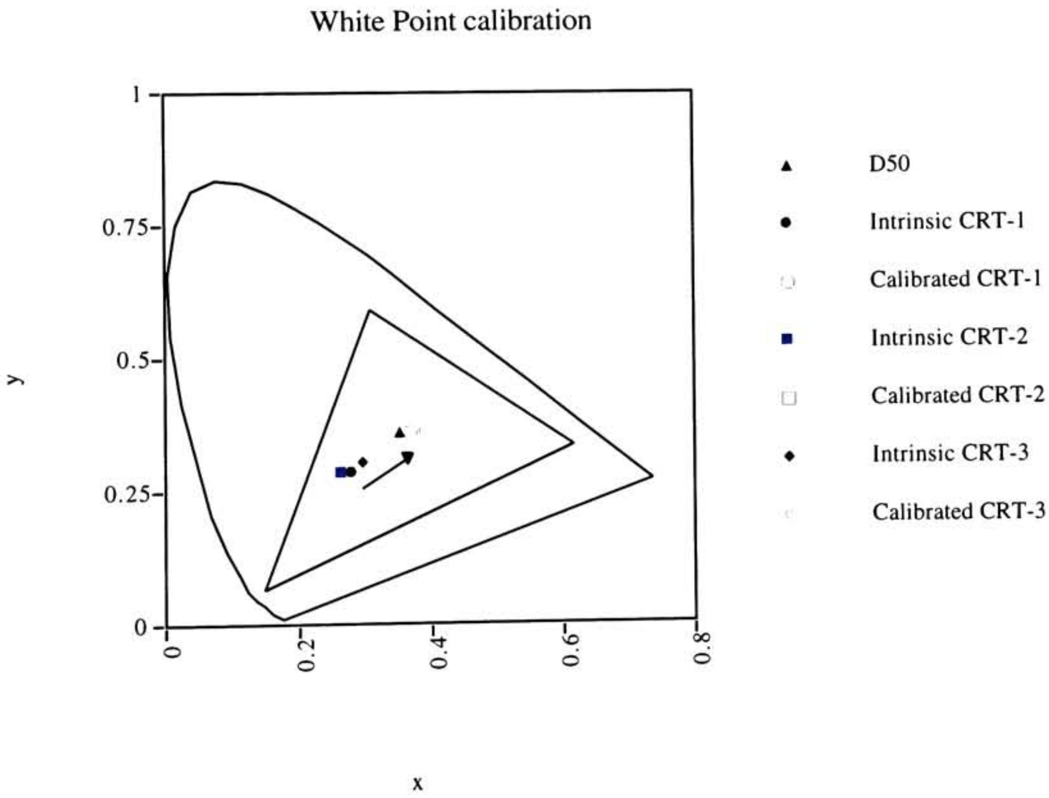


Figure-8. The chromaticity diagram of white point calibration

Figure-8 shows that all the intrinsic CRT white points converge to the target–D50 white point. This test proves that the ColorTron Calibrator is capable of bringing the CRT's intrinsic white point to a target white point.

Summary

Typeface WYSIWYG was successfully achieved through technology such as Postscript font, True type font, and ATM. Color WYSIWYG is the next goal. Color Management System provides the opportunity to achieve Color WYSIWYG on a desktop system.

This study deals with only a small part of CMS. This study focuses only on hardcopy-softcopy agreement through CMS procedure. The major control factors in this study are CRT gamma and CRT white point.

This section introduced basic terminology on CMS technology, CRT contrast and brightness setting, and CRT calibration. A preliminary test on CRT calibration shows that the calibration tool, the ColorTron Calibrator, is competent in setting the CRT to the target condition, i.e., gamma 1.8 and D50 white point. Although the result of calibration is not perfect, it is still important and necessary for this study to use it as the starting point for further research.

It is hope that this study could find out the workable control factors that provide the end user leverage to work with CMS technology more efficiently.

Endnotes

1 The reproduction of colour in photography, printing & television, Fourth edition, by Dr. R. W.G. Hunt. p.50. Fountain Press, 1987.

2 "An explanation of monitor gamma," by Robert W. Berger. Online. Internet, Feburary, 1996 at http://www.vtiscan.com/~rwb/gamma.html,

3 "The ColorTron monitor calibrator," p.17.ColorTron User manual, First edition, Light Source Computer Images, Inc. (Light Source), October, 1994.

Chapter 2

Background Theory

Mathematical Management of Color

Color was a phenomenon until Sir Isaac Newton (1642-1727) discovered it as an identifiable property of light, and not until J. C. Maxwell (1831-79) discovered the wave theory of light did color acquire a good footing. Maxwell showed that light is just a form of electromagnetic energy that could be described as electromagnetic "waves." Because of Maxwell's work, we can now assign specific numbers to different points in the visible spectrum.

The work of Thomas Young (1773-1829) indicated that the eye could not possibly have a receptor for every possible wavelength. Hermann von Helmholtz (1821-94) put all this together and first described the idea of red, green, and blue receptors in the eye and drew the first illustration of their spectral curves.

Based on these scientists' theories, a more practicable color quantitative system was specified in a CIE (Commission Internationale d'Éclairage) meeting in 1931.

CIE System

In 1931, the Commission Internationale d'Éclairage (CIE) or International Commission on Illumination developed its system for color measurement. The CIE defined the standard illuminants and the standard observer. A color in the CIE system is specified by its tristimulus values. Tristimulus values X, Y, and Z of a color are the integral product of multiplying spectral reflectance factors of the object color with the spectral power distribution of the illuminant and with the color matching functions of the standard observer through the visible wavelengths as shown in the following equations:

$$X = k\int_{380}^{760} S(\lambda)R(\lambda)\bar{x}(\lambda)d\lambda$$

$$Y = k\int_{380}^{760} S(\lambda)R(\lambda)\bar{y}(\lambda)d\lambda$$

$$Z = k\int_{380}^{760} S(\lambda)R(\lambda)\bar{z}(\lambda)d\lambda$$

$$k = \frac{100}{k\int_{380}^{760} S(\lambda)\bar{y}(\lambda)d\lambda}$$

where S(λ) is spectral power distribution of a given illuminant or light source; R(λ) is spectral reflectance factor of a colored object, $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ are 2° or 10° color matching functions of the standard observer; k is a normalizing factor for luminance; and dλ is the wavelength interval. While the Y tristimulus value correlate with lightness, the X and Z tristimulus values do not correlate with perceptual color attributes, hue and chroma.

The comparison in terms of hue and chroma differences from two different sets of tristimulus values represent an ordinal scale. The CIE, hence, established the chromaticity coordinates x, y, and z which are mathematical transformations of the tristimulus values X, Y, and Z:

$$x = \frac{X}{X+Y+Z}$$
$$y = \frac{Y}{X+Y+Z}$$
$$z = \frac{Z}{X+Y+Z}$$

where x, y, and z are chromaticity coordinates and X, Y, Z are tristimulus values. When the colors of the Munsell system are plotted in the CIE chromaticity diagram, the spacing of the Munsell loci shows a lack of uniformity. Because the Munsell system is based on equal visual differences, this lack of uniformity indicates that equal distances on the CIE chromaticity diagram do not represent equal visual difference.

One of the uniformity color scales, which was developed in 1976 to improve the uniformity of visual perception of the CIE system, is the CIE L* a* b* system. The L* a* b* figures are the result of a nonlinear, mathematical transformation of the tristimulus values X, Y, and Z. The establishment of the CIELab color scale relies on the opponent color concept: the color that is perceived by the human eyes cannot be both light and dark at the same time, both red and green at the same time, or both yellow and blue at the same time. The lightness in the CIELAB color scale is symbolized with L*, redness and greenness are expressed as +a* and -a* respectively, and yellowness and blueness are defined as +b* and -b* respectively. The L* a* b* values are calculated by the following equation:

$L^* = 116F(Y) - 16$

$a^* = 500[F(X) - F(Y)]$

$b^* = 200[F(Y) - F(Z)]$

where

$F(X) = (X / Xn)^{1/3}$ when X/Xn > 0.008856

$F(X) = 7.787(X / Xn)^{1/3} + 0.1379$ when X/Xn ≤ 0.008856

$F(Y) = (Y / Yn)^{1/3}$ when Y/Yn > 0.008856

$F(Y) = 7.787(Y / Yn)^{1/3} + 0.1379$ when Y/Yn ≤ 0.008856

$F(Z) = (Z / Zn)^{1/3}$ when Z/Zn > 0.008856

$F(Z) = 7.787(Z / Zn)^{1/3} + 0.1379$ when Z/Zn ≤ 0.008856

Where X, Y, and Z are tristimulus values of the given color and Xn, Yn, and Zn are tristimulus values of the illuminant or the reference white.

In the CIELAB system, the other two useful parameters are psychometric chroma (C^*_{ab}) and psychometric hue angle (h°_{ab}). C^*_{ab} and h°_{ab} are derive from a* and b* by the following equations:

$$C^*_{ab} = [(a^*)^2+(b^*)^2]^{1/2}$$

$$h^\circ_{ab} = \arctan (b^*/a^*)$$

Color variation between a sample color and a standard color is determined by tCIELAB color difference (ΔE^*_{ab}) which indicates how much a sample differs in chroma, hue, and lightness from a standard. To calculate the color difference, the following equation is used:

$$\Delta E^*_{ab} = [(\Delta L^*)^2+(\Delta a^*)^2+(\Delta b^*)^2]^{1/2}$$

Where ΔE^*_{ab} is the total perceived color difference and ΔL^*; Δa^*, and Δb^* are the differences in L*, a* b* coordinates between a sample and a standard.

Color Space Transformation

Because color imaging devices speak different color languages, the approach to manage color among different imaging devices is to translate the device color language into an independent color space so the devices can communicate with each other through the independent color space. CIE color system provides the independent color space for devices to communicate with each other.

The device color translates into CIE space can by Neugebauer Equation or by high order polynomial regression:

Neugebauer Equation:

$F_W=(1-c)(1-m)(1-y)$

$F_C=c(1-m)(1-y)$

$F_M=m(1-c)(1-y)$

$F_Y=y(1-c)(1-m)$

$F_R=my(1-c)$

$F_B=cm(1-y)$

$F_K=cmy$

Where: F_W, F_C, F_M, F_Y, F_R, F_G, F_B , and F_K sequentially denote the fractional areas of Paper, Cyan, Magenta, Yellow, Red, Green, Blue, and Three-Color Overprint.

c denotes the fractional area covered by cyan dot.

m denotes the fractional area covered by magenta dots.

y denotes the fractional area covered by yellow dots.

cmy denotes the fractional area covered by cyan , magenta, and yellow dots, or the three-color overprint.

1-c denotes the area not covered by cyan dots.

1-m denotes he area not covered by magenta dots.

1-y denotes the area not covered by yellow dots.

(1-c)(1-m)(1-y) denotes the area not covered by cyan, magenta, and yellow dots, or white (paper).

$$X_{PC}=F_W X_W+F_C X_C+F_M X_M+F_Y X_Y+F_R X_R+F_G X_G+F_B X_B+F_K X_K$$

$$Y_{PC}=F_W Y_W+F_C Y_C+F_M Y_M+F_Y Y_Y+F_R Y_R+F_G Y_G+F_B Y_B+F_K Y_K$$

$$Z_{PC}=F_W Z_W+F_C Z_C+F_M Z_M+F_Y Z_Y+F_R Z_R+F_G Z_G+F_B Z_B+F_K Z_K$$

Where X_{PC}, Y_{PC} and Z_{PC} are the computed tristimulus values of a printed color; X_W, Y_W, Z_W,...are the measured tristimulus values of the eight primaries consecutively; and F_W, F_C, F_M,... and F_K are the weighting fractional area of the eight primaries..

Another color space transformation scheme can be achieved by sampling devices and building a relationship equation using a statistics approach. An example of high order polynomial regression between device RGB and CIEXYZ can be formulated as:

$$X=a_{11}R+a_{12}G+a_{13}B+a_{14}RG+a_{15}RB+a_{16}GB$$

$$Y= a_{21}R+a_{22}G+a_{23}B+a_{24}RG+a_{25}RB+a_{26}GB$$

$$Z= a_{31}R+a_{32}G+a_{33}B+a_{34}RG+a_{35}RB+a_{36}GB$$

Where X, Y and Z are tristimulus values and R, G, B are linear terms from device color and RG, RB, GB are cross terms of device color. a_{11}, a_{12},....a_{36} are regression weighted factors of the matrix.

Summary

The color space transformation involved complex mathematical calculation. This study is not trying to calculate color space transformation between devices. This study is trying to use the knowledge to attain a better control on CMS. Finding out how to control CMS applications is the main purpose in this research.

Chapter 3

Review of Literature

This study aimed to achieve best softcopy-hardcopy agreement under limitation of devices and the imaging capability available in the market today. The review of literature was therefore mostly focus on how to render the CMS procedure provide by CMS vendors and included related documents on the theory of color space and color space transformation.

The ColorTron user manual had clear instruction on how to setup the brightness and contrast. A similar discussion was found in Charles A. Poynton´s ,"Black Level" and "Picture," copyright 1995/06/08.

The ColorTron user manual explained that gamma=1.8 is for compensating of dot gain related to the Apple Laserwriter. A similar description is found in Charles A. Poynton's Frequently Asked Questions about Gamma, copy right 1995/05/28.

A technical report from M.D. Fairchild titled A Simple Printer Calibration Technique for "Good Enough" Color Reproduction, January 1994, mentions another gamma factor to compensate viewing condition from CRT(dim) to hardcopy (bright). The ambient factor will be explored in this study.

This technical report demonstrates a simple calculation of color space transformation between CRT and printer by correlating printer color to CRT color through a one dimensional look-up table (LUT) applied to each RGB image channel to adjust the tone reproduction and a 3-by-3 matrix transformation that adjusts the hues of output image.

In 1993, a paper titled CRT Colorimetry Part I: theory and practice, was present by R. S. Berns, R. J. Motta, and M.E. Gorzynski. In this paper, the relationship between

digital information and the color of the radiant output of computer-controlled CRTs display as described by CIE colorimetry was derived.

Some related documents on the Internet discussed the relation of CRT gamma and the World Wide Web publishing.

A CGSD (Computer Graphic System Development Corporation.) paper titled Gamma Correction Explained, explained the default gamma setting on different platforms and the required gamma correction for exchanging image information among different platforms. For example, the Sun station and PC platform have no gamma correction in their system, and each has an intrinsic gamma roughly 2.5. The Mac platform has a built-in gamma correction in its system that brings the CRT appearance to 1.8 gamma. The SGI has a roughly 1.7 gamma. Thus, when exchanging image information among different platforms, application of an appropriate gamma correction is necessary.

A CGSD document Gamma Correction in Mac gamma Control Panel, explains how Knoll software rewrites the look-up table to achieve target gamma.

A CGSD document Gamma Correction and Color Space, demonstrates how gamma affects hue reproduction. An example of test patch with R 80%, G 20% and B 20% in a 1.0 gamma CRT will reproduce an R 57%, G0%, and B 0% in a gamma 2.5 CRT. The hue is dramatically changed. It demonstrates gamma not only affects the tone reproduction but also influences hue reproduction significantly.

How Photoshop manages color reproduction is investigated as the basic notion of desktop image reproduction process.

The CRT RGB to hardcopy CMYK conversion under Photoshop could be summarized as a block diagram shown in Figure-9.

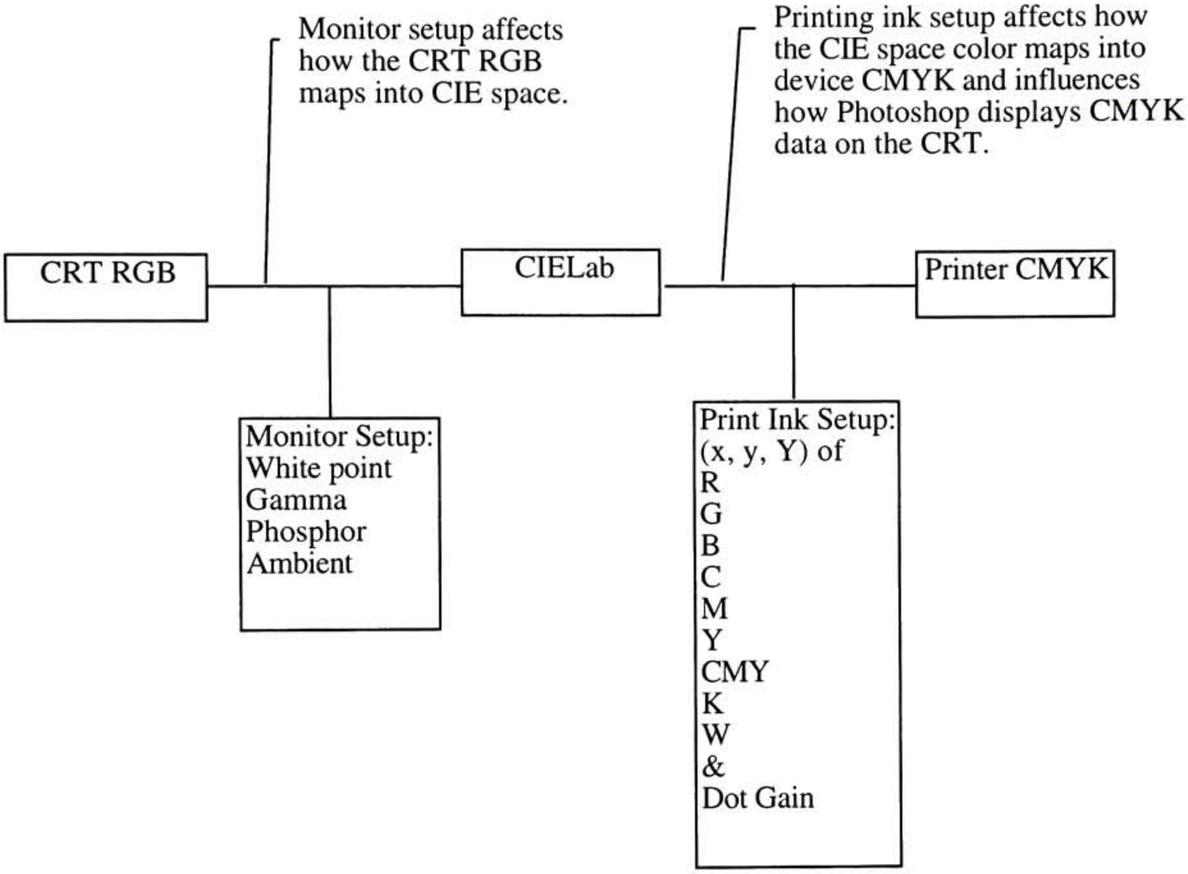


Figure-9. The CMS in Photoshop

Chapter 4

The Hypothesis

Statement of the Hypothesis

This study tries to demonstrate that the proper CRT profile setting to achieve the best match between CRT and hardcopy is system dependent. Every system needs an external colorimetric sensor to provide an exact value which will result in better performance then the default parameters: D50 white point and 1.8 gamma.

Based on the objectives, theories, and relevant research work, mentioned in the preceding chapters, the hypothesis for this research is:

H_{01} : There is no significant perception difference in softcopy-hardcopy agreement under dark ambient light among CRT images converted from different CRT profile parameters.

The hypothesis was written in the null form. If the hypothesis is rejected than the alternative (shown as H_{0a}) hypothesis can be accepted.

H_{0a}: There is significant perception difference in softcopy-hardcopy agreement under dark ambient light among CRT images converted from different CRT profile parameters.

Chapter 5

Methodology

5.1. Delimitation of the Study

Color perception is affected by physical and psychophysical factors. Managing color is complicated because of device limitations and perceptual factors. The following controls are necessary in order to have a manageable study:

1. Gamut mapping is beyond the scope of this study. "Perceptual Match" is the only rendering style used in this study.
2. Photoshop has its own color transformation function which is different from those produced by Color Management Systems. This study focuses only on the ICC-based CMS approach.
3. Both the viewing luminance and the CRT white point are set to D50. No other luminance standard is examined in this study.
4. All gamma analyses in this study are based on normalized data. So it is possibly see different results from other research based on different definitions and calculations on gamma.

5.2 Experimental Design

The experiment is divided into two parts. The first part is an observer experiment which tests the softcopy-hardcopy agreement via 6 different CRT profiles. These 6 profiles are generated from the combination of 3 different gamma and 2 white-points. The three gamma levels are 1.8, 2.15 and 2.4; the two different white point are D50 and D65.

The second part employs a colorimetric instrument (Minolta CA-100 for CRT data, X-Rite 948 for hardcopy data) to analyze the color reproduction behavior of devices and provide information for testing visual agreement.

Further analysis of hardcopy to CRT agreement was possible based on the hypothesis testing and colorimetric analysis.

5.2.1 Equipment and Material

The following were used:

Computer Platform: PowerMac 7100/80, MacOS System 7.5 with ColorSync 2.0

Retouching Application: Adobe Photoshop 3.0 with ColorSync Plug-in module

CRT: Apple 16" MultiSync color display

Hardcopy device: Imation Rainbow

CRT profiling tool: ColorTron II and ColorBlind 2.5

Hardcopy profiling tool: ColorBlind 2.5 w/ X-Rite DTP-51

CRT verification tool: Minolta CA-100

Hardcopy colorimeter: Xrite 948

Statistics software: Excel, JMP, Cricket Graph III

D-50 viewing booth: GTI Soft-View

5.2.2 Preparation of Device Profiles

1. Create a hardcopy (3M Rainbow dye sublimation printer) profile using ColorBlind 2.5 and X-Rite DTP-5 1.
2. Calibrate CRT with ColorTron II.
3. Prepare the test CRT profiles from ColorBlind 2.5:
   3.1 Gamma = 1.8, White point = D50.
   3.2 Gamma = 1.8, White point = D65.
   3.3 Gamma = 2.15, White point = D50.
   3.4 Gamma = 2.15, White point = D65.
   3.5 Gamma = 2.4, White point = D50.
   3.6 Gamma = 2.4, White point = D65.

5.3 Part I Observer Experiment

Two SCID (Standard Color Image Data) images were output to the Imation Rainbow as hardcopy reference and evaluated in a D-50 viewing booth. The SCID image is a set of digital data specified by ISO (International Standard Organization, ISO 12640) for evaluation of change in image quality during coding, image processing (including transformation, compression, and decompression), film recording, or printing which can be used for research, development, product evaluation, and process control.

The same SCID CMYK file was then converted to RGB with Imation Rainbow as source profile and the 6 different CRT profiles mentioned above were prepared as output profile, each in turn.

These 6 images were then judged by paired comparisons through a Macromedia Director interface with Lingo programming language which is capable of displaying and

collect data by interacting with users. The ranking and paired comparison was the major information needed for this study.

The paired comparison method in this study was used as follows: 11 judges was asked to compare the members of a set of six CRT images in all possible pairs. The judge merely indicated which of each pair of CRT images is a better appearance match to the hardcopy reference.

There was no right or wrong answer. Each judge used his/her own criteria for appearance match. From the results of the experiment, it was known whether or not the judge was consistent in applying whatever criteria (s)he uses, and if there are several judges, it would be known whether or not they agreed with each other.

A judge's inconsistency is shown by the presence of one or more triads in his data. Example of triad: a judge prefers item A to item B, and item B to C, but prefers item C to item A. The inconsistent observer samples (with triad) were discarded; the consistent samples were used to conduct a statistics test to test the agreement among judges. Refer to Appendix C for details on the paired comparison procedure.

5.4 Part II. Colorimetric Analysis

This part of the experiment employed colorimetric analysis for the test image. Colorimatric analysis makes it possible to reveal the correlation between the visual perception difference and the colorimetric data difference. The information was useful for future testing and fine-tuning the profile parameters.

5.4.1 Preparation of Hardcopy Colorimetric Data

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
C	0	0	0	0	0	1	0	5	71	88	91	93	99	99	98	62	0
M	0	0	0	0	0	95	75	2	0	1	0	0	50	88	99	96	94
Y	0	0	0	0	0	99	95	89	97	99	87	49	0	0	3	1	42
K	0	25	50	75	100	0	0	0	0	0	0	0	0	0	1	1	0

Figure-10. Test patches design

Table-3 Colorimetric data from Rainbow in CIE x, y, Y format

	1	2	3	4	5	6	7	8	9
x	0.3381	0.3442	0.3434	0.323	0.2926	0.6091	0.5581	0.4391	0.3334
y	0.348	0.3566	0.356	0.3513	0.3333	0.3394	0.3729	0.4785	0.5285
Y	87.08	52.47	23.32	9.21	2.21	18.38	26.41	71.49	30.81
	10	11	12	13	14	15	16	17	
x	0.2896	0.2656	0.2253	0.1971	0.218	0.2287	0.3481	0.5279	
y	0.544	0.5102	0.3965	0.2424	0.1753	0.1537	0.2128	0.3017	
Y	24.61	23.42	23.3	11.57	4.88	3.36	7.83	21.49	

1. Design test patches with 5 neutrals of different lightness and 12 saturated color in CMYK format as shown in Figure-10.
2. Output the test patches to Imation Rainbow.
3. Measure the samples with X-Rite 948 so data is in the form of a table as seen in Table-3.

5.4.2 Preparation of Softcopy Colorimetric Data

1. CMYK to RGB transformation

   In Photoshop, acquire the CMYK test patches through ColorSync plug-in module using the following settings:

Quality: Best

Source profile: Rainbow

Output Profile: CRT profile

Matching Style: Perceptual

2. Collect six sets of CRT colorimetric data using the CA-100 by reading the test patches from CRT surface. Each test patch was enlarged to fill at least 2/3 portion of the CRT display area to avoid possible noises from the surround color.

5.4.3 Analysis of Colorimetric Data

The colorimetric data of softcopy and hardcopy was analyzed in terms of ΔE, ΔC^* and ΔH. The relationship of colorimetric differences and the observer experiment results was further investigated.

Chapter 6

The Results

Test Results

For the hypothesis:

> There is no significant perception difference in softcopy-hardcopy agreement under dark ambient light among CRT images converted from different CRT profile parameters.

The hypothesis is rejected. There is significant perception difference in softcopy-hardcopy agreement under dark ambient light among CRT images converted from different CRT profile parameters.

The rejection of the hypothesis is based on the result described.

The Influence of the CRT Profile

The score of the non-triads' samples from **Three musicians** image and **Orchid** image displays as Figure 11 and Figure 12.

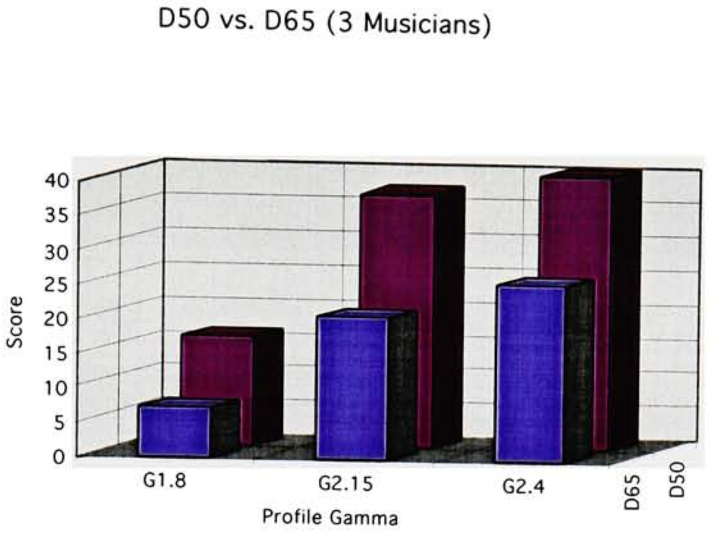


Figure-11. Three musicians non-triads samples under dark ambient light.

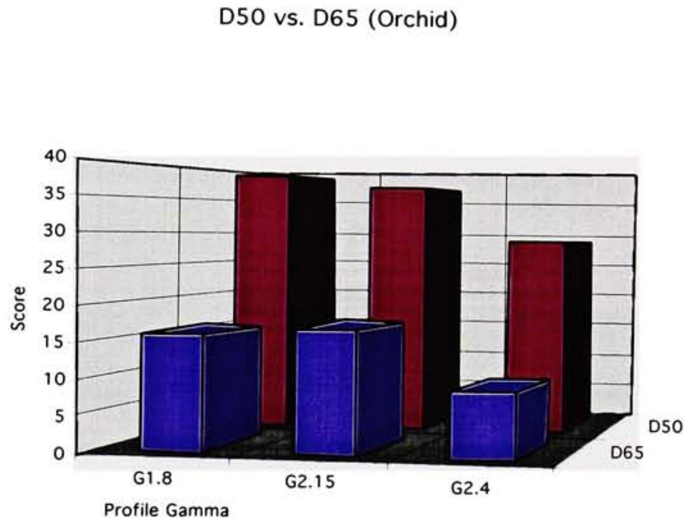


Figure-12. Orchid non-triads samples under dark ambient light.

The statistics processed from Table 4 indicates that the judges are capable of ranking the differences among images reproduced with different CRT profiles and the agreement among judges is consistent. The first hypothesis is thus rejected.

Table 4. Non-Triads samples and the statistics testing

3 Musicians

	Pict1	Pict2	Pict3	Pict4	Pict5	Pict6	
Rank	2	1	6	3	5	4	
	2	1	5	3	6	4	
	4	1	6	2	5	3	
	2	1	5	3	6	4	
	2	1	5	3	6	4	
	2	1	5	3	6	4	
	2	1	5	4	6	3	
Critical							335
Sum	16	7	37	21	40	26	
Average	24.5	24.5	24.5	24.5	24.5	24.5	
Sum-Ave	-8.5	-18	12.5	-3.5	15.5	1.5	
Square	72.3	306	156	12.3	240	2.25	790
Coefficient							0.92

Orchid

Pict1	Pict2	Pict3	Pict4	Pict5	Pict6	
4	2	6	3	5	1	
6	3	5	2	4	1	
6	1	5	3	4	2	
6	3	5	2	4	1	
6	1	5	3	4	2	
5	3	6	2	4	1	
6	3	5	2	4	1	
						335
39	16	37	17	29	9	
24.5	24.5	24.5	24.5	24.5	24.5	
14.5	-8.5	12.5	-7.5	4.5	-16	
210	72.3	156	56.3	20.3	240	756
						0.88

Testing value

Number of Pictures	Numbers of Judges (J)			
	4	5	6	7
3	---	64.4	103.9	157.3
4	49.5	88.4	143.3	217.0
5	62.6	112.3	182.4	276.2
6	75.7	136.1	221.4	335.2

Critical Value

Further Analysis

The perception differences between different type of images

The test results show that the evaluation of the softproof (softcopy-to-hardcopy agreement) is image-dependent; different types of images need different profiles to achieve the best appearance match.

The three musicians image is a normal-key image with various skin tones. The orchid image appears to be a high-key image because the observers paid more of their attention to the contrast of the white plate. (Known from a brief interview with observers).

Figure-11 and Figure-12 show that the score distribution between three musicians and orchid is different. In the test for the three musician image, the observers prefer images prepared from the profile with D50 and Gamma 2.4. But in the test for the orchid image, they prefer the image prepared from the profile with D50 and Gamma 1.8.

Inverse relationship between profile gamma and image gamma

The image gamma of the hardcopy is approximately 1.8. The CRT profile gamma tested in the first run are 1.8, 2.15 and 2.4, and the corresponding image gamma after the CMS process are 2.0, 1.7 and 1.5 respectively (see Figure 13.)

$y = 1.003x^{1.819}$ $r^2 = 0.995$
(Hardcopy)

$y = 0.819x^{1.664}$ $r^2 = 0.963$
(Profile 2.15)

$y = 0.787x^{2.023}$ $r^2 = 0.966$
(Profile 1.8)

$y = 0.840x^{1.509}$ $r^2 = 0.966$
(Profile 2.4)

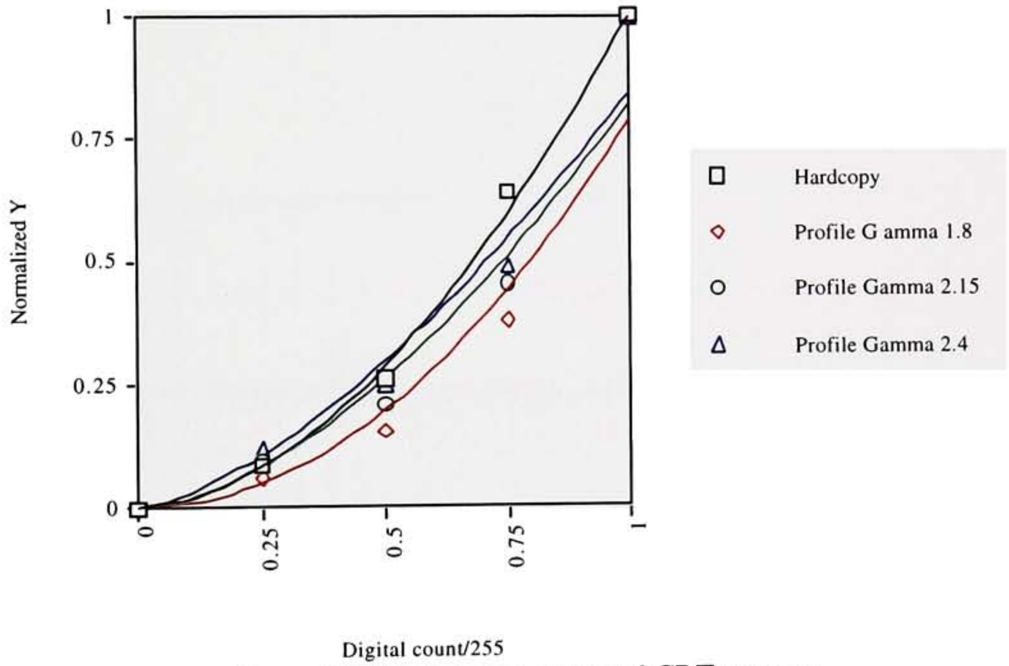


Figure 13. Hardcopy gamma and CRT gamma

The result seen in Figure 13 shows that the profile gamma and CRT image gamma have an inverse relationship.

A mathematical approach which can predict the CRT image gamma from CRT profile gamma or vice versa could be developed from this test. By applying the power curve fitting function between CRT profile gammas and its corresponding image gammas,

we obtained an equation that can predict the CRT image gamma from CRT profile gamma (or vice versa). The equation and power curve fitting is shown in Figure-14.

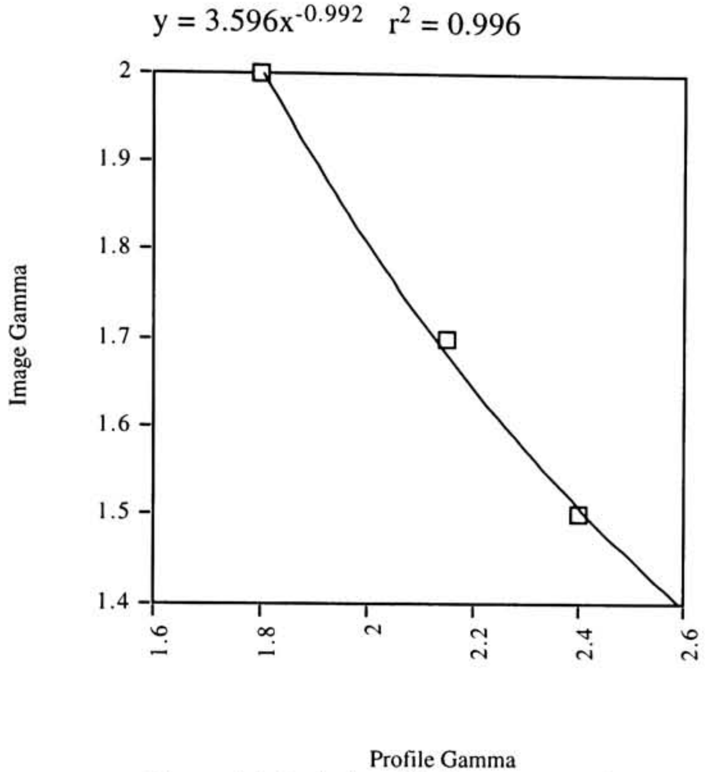


Figure 14. Relationship between profile gamma and image gamma

<u>The image reproduction with different profile white point</u>

Since the standard light source is D50 in the Graphic Arts industry, the test here focused on D50: the viewing booth was set to D50; the CRT white point was calibrated to D50 by ColorTron II. It is expected that by assigning the D50 into the monitor profile will generate the best softcopy-to-hardcopy agreement. The results were as expected. The other profile white point tested here is D65 which represents the standard white point of the Macintosh 16" CRT page white.

The ranking of both the three musicians and orchid images prepared with D50 profiles surpass the ranking of the images reproduced with D65 profiles at each of the three gamma levels. (See Figures 11, 12.)

The colorimetric test used a 25% gray patch as a reference to verify the white point reproduction. The colorimetric data of white point of the hardcopy and the corresponding CRT images reproduced with D50 and D65 profile white point shown in Figure-15.

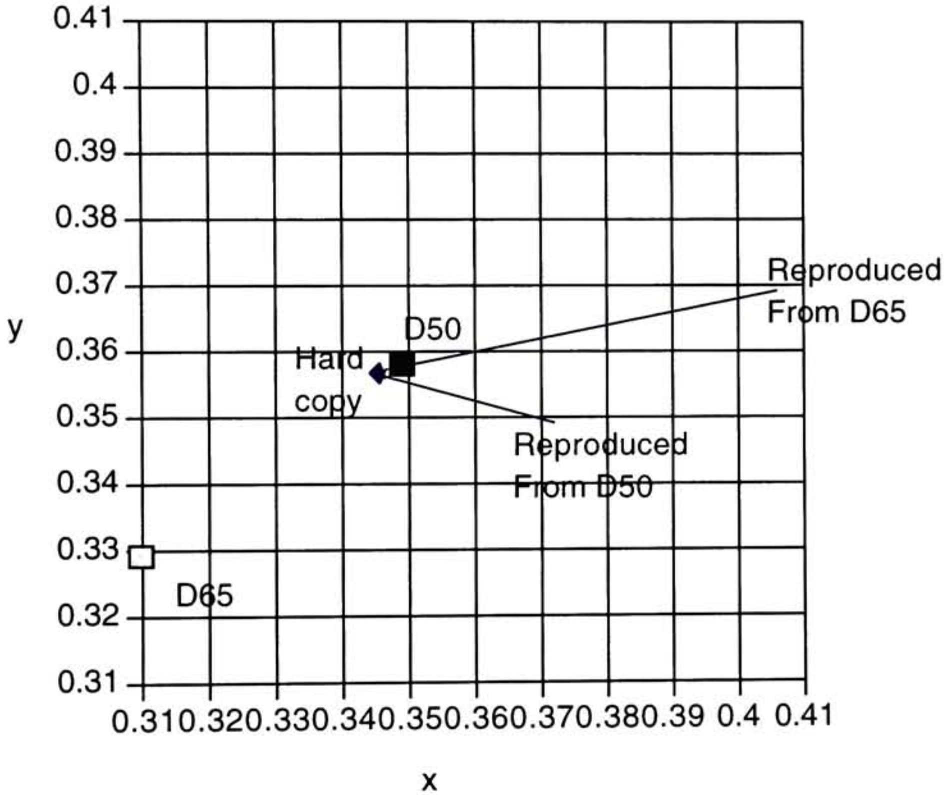


Figure-15. White point reproduction

Figure 15 shows that the CRT image reproduced with the D50 profile has a smaller distance to the hardcopy compared to the CRT image reproduced with the D65 profile. The results agree with the observer experiment.

Figure-15 also indicates that the neutral color reproduced from the monitor profile has an inverse relationship with the profile white point. When the image is assigned with a more bluish white point (D65) in the profile, the neutral color has a reddish shift.

The agreement between colorimetric data and human perception

The colorimetric differences (ΔE) among images reproduced with different monitor profiles (calculated from the reference patches mentioned in Chapter 5) is in column 2 of Table 5. The colorimetric ranking is in column 3. The perception ranking of the three musician image is in column 4.

The information indicates that the perception ranking is slightly different from the colorimetric ranking. Nevertheless, the colorimetric data is still a useful tool for analyzing the perception difference.

Table 5 Comparison of colorimetric data and observer experiment

Profile	ΔE	Ranking (Colorimetric)	Ranking (Perception)
G18D50	14.18	2	2
G18D65	16.49	1	1
G215D50	10.59	5	5
G215D65	13.02	4	3
G24D50	9.09	6	6
G24D65	14.05	3	4

Chapter 7

Summary and Conclusion

This study attempts to figure out the best parameters on monitor profiles which can achieve the optimum softcopy-to-hardcopy agreement. Via both observer experiment and colorimetric data, the hypothesis investigated the influence of the different monitor profile parameters–gamma and white point–on image reproduction from hardcopy to softcopy. The results indicated that the different profile parameters did affect reproduction and default profile parameters (Gamma=1.8, white point=D50) cannot produce the optimum match between hardcopy and softcopy. The D50 profile white point did provide a better match on both images as expected; but the 1.8 profile gamma did not generate the optimum match on one of the images–the orchid one. This information revealed that the perception of the softcopy-to-hardcopy agreement is image dependent causing difficulty when applying the CMS solution to all types of images. Human intervention is still important during the image reproduction process when using CMS technology.

This study also found that there is a systematically inverse relationship between profile parameters and its corresponding CMS processed images. Profile gamma has a clear and predictable inverse relationship with its reproduced image gamma; yet we did not perceive this kind of inverse relationship on the profile white points as clear as in profile gammas. Nevertheless, it is still possible to build a mathematical approach to predict the relationship between profile parameters and corresponding images.

By analysis of the colorimetric data and the observer experiment, this study found that the CIELab system is capable of predicting color matching only on normal key images

(three musicians). For the study of looking for the optimum profile parameters, the observer experiment is still needed and important.

Conclusion of the Hypothesis

From the test results, the following is the conclusion regarding the hypothesis:

Hypothesis:

There is no significant perception difference in softcopy-to-hardcopy agreement under dark ambient light among CRT images converted from different CRT profile parameters.

Rejected

The influence of the CRT profile parameters (gamma and white point) on the image data conversion between hardcopy and softcopy is significant.

Recommendation for Further Study

It is important to consider the maximum device brightness differences when calculating image gamma since the maximum brightness of the devices will influence the perception substantially.

The calculation of the image gamma in this test was based on gray scale black dot coverage. Calculation based on TAC (Total Area Coverage) will reveal more complete information of the CMYK device. Considering the discussion, image gamma calculation methodology needs more investigation.

The same approach used in this study could be applied to the testing of the WYSIWYG solution—the image reproduction from CRT to printer.

Since the CMS process is based on a mathematical model, the error is systematically. It is possible to correct the system error by using a more aggressive approach to manipulate the CRT profile and obtain the optimum match between softcopy and hardcopy.

The perceptual rendering is the only rendering intent tested in this study. Colorimetric rendering and saturation rendering intent are recommended for further study.

References

1. "Color and Color-Difference Measurement," by F.W. Billmeyer, M. Saltzman, *Principles of color technology*, John Wiley & Sons. 1981.
2. "Some hidden requirements for device-independent color imaging" by M. D. Fairchild, *1992 TAGA Proceedings* , 1994.
3. "CRT Colorimetry Part I: Theory and Practice," by R. S. Berns, R. J. Motta, and M. E. Gorzynski, *Color Res. Appli.*, 18 299-314 (1993).
4. "A simple printer calibration technique for "Good Enough" color reproduction of color images" by M.D. Fairchild, *Munsell Color Science Laboratory Technical Report*, January 1994.
5. "Benchmarking default settings and Kodak Color Sense," by R.L. Alfvin, *1994 Color Modeling Lab Report*, March, 1994.
6. ColorTron User Manual, First edition, Light Source Computer Images, Inc. (Light Source), October, 1994.
7. "Frequently Asked Questions about Gamma," by Charles A. Poynton, Online, Internet, May 1996 at http://www.inforamp.net/~poynton.
8. "Black Level and Picture," by Charles A. Poynton, Online, Internet, May 1996 at http://www.inforamp.net/~poynton.
9. "Gamma Correction Explained," Computer Graphic System Development Corporation. 1996.
10. "Gamma Correction in Mac Gamma Control Panel," Computer Graphic System Development Corporation. 1996.
11. "Gamma Correction and Color Space," Computer Graphic System Development Corporation. 1996.

12. "Tone Reproduction," *The Reproduction of Colour in Photography, Printing & Television, Fourth Edition*, by Dr. R. W. G. Hunt, Fountain Press, 1987.

13. " A Comparison of Algorithms for Mapping Color Between Media of Differing Luminance Ranges" by J.A. Stephen Vigiano and C. Jeffery Wang, *1992 TAGA Proceedings*, 1992.

14. Graphic Technology - Prepress digital data exchange - Standard Colour data (SCID), International Organization for Standardization, 1995.

15. The reproduction of colour in photography, printing & television, Fourth edition, by Dr. R. W.G. Hunt, Fountain Press, 1987.

16. "An explanation of monitor gamma," by Robert W. Berger,Online, Internet, February at http://www.vtiscan.com/~rwb/gamma.html.

17. "Subjective Color Evaluation Using Paired Comparison," Al Rickmers, Rochester Institute of Technology.

18. ColorSync 2.0: White Paper, Apple Computer, Nov. 28,1995.

19. All about ColorSync 2.O, Apple Computer, 1995.

Appendices

Appendix A

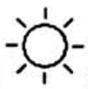
Contrast and Brightness Setting

Appendix A

Contrast and Brightness Setting

A preliminary test on CRT setting and calibrating was conducted. The definition of brightness and contrast was discussed in the preliminary test. The calibration from different setting was investigated. The proper criterion on CRT brightness/contrast setting and calibration was addressed in this preliminary study.

Before implement a CMS procedure into a desktop system; the first issue is the device calibration. Prior to the CRT calibration, the brightness and contrast setting are the first issue need to be addressed.

There are arguments in literature upon the definition of brightness and contrast. The icon  as seen in all monitors, is referred as "brightness" control. It affects the overall intensity control of CRT display. When increase the brightness, the intensity of all output value is raised by an equal value (refer to Figure A-1). It mainly affects shadow contrast of a CRT display. Consequently, it was by Charles Poynton as "black level control" (refer to Figure A-2).

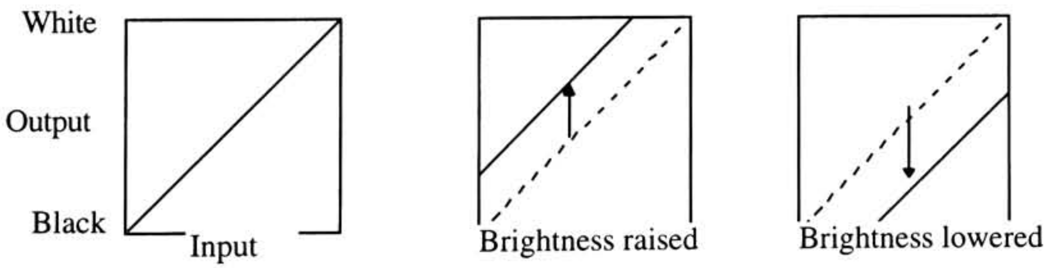
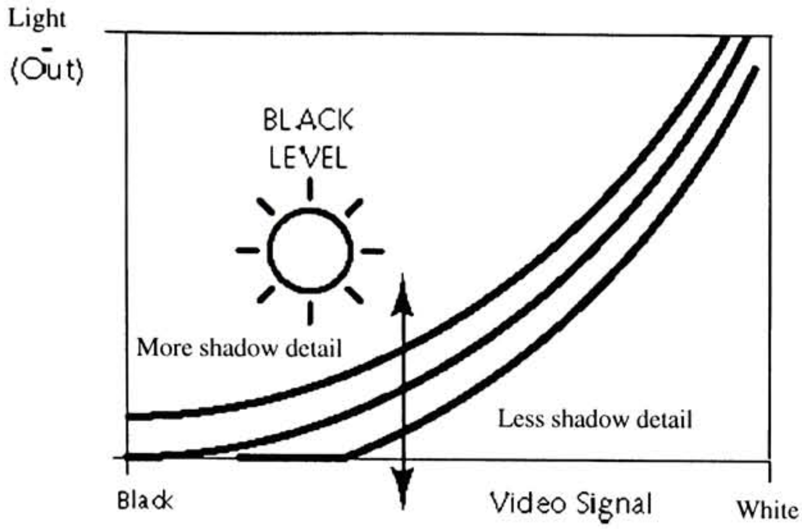


Figure A-1. When the "brightness" knob was adjusted, the overall intensity changed.



source: Charles A. Poynton, Online.

Figure A-2. The brightness setting affects mostly dark areas.

The icon  , as seen in all monitors, is referred as “contrast” control. It controls the difference between brightness level (refer to Figure A-3). The contrast control is also referred as the “picture control “ by Poynton (refer to Figure. A-4).

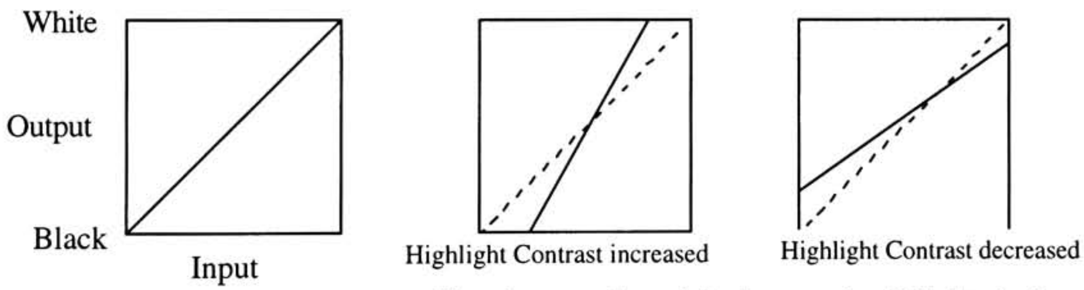
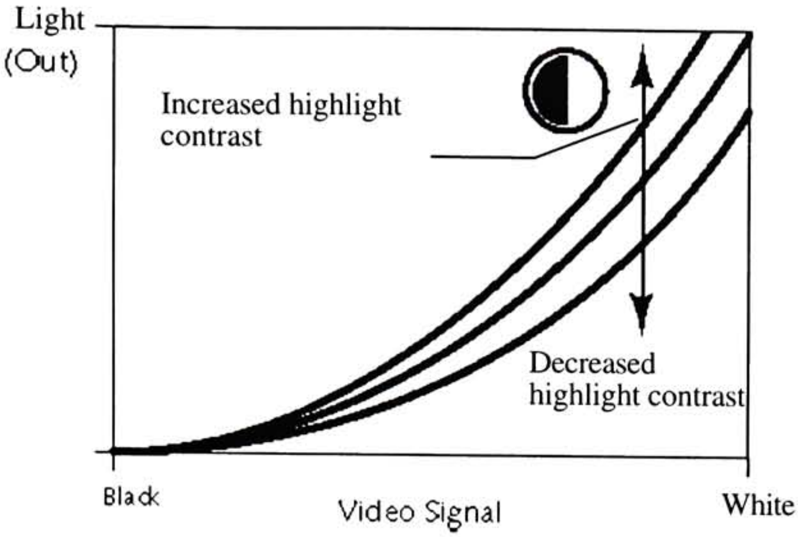


Figure A-3. When the “contrasts” knob was adjusted, it changes the hi-light-shadow relation.



source: Charles A. Poynton, Online.

Figure A-4. The "picture" setting affects mostly on bright area

From Figure-A2 we see that brightness control affects all of the display range but has more impact on the dark area. The proper setting of brightness is adjusted to the balance point or threshold, low enough that a black area of the picture emits no light, but high enough that setting the control any higher would cause the area to become a dark gray. If the setting is too low, the CRT cannot distinguish the input of low digital count. The low digital count will show the same darkness on CRT. If the setting is too high, we lost the blackest display of CRT thus decreasing the CRT display range. The same situation happened when we adjusted the contrast control (refer to Figure A-4). The proper setting is to increase the contrast as high as possible but avoid clipping on high digital count.

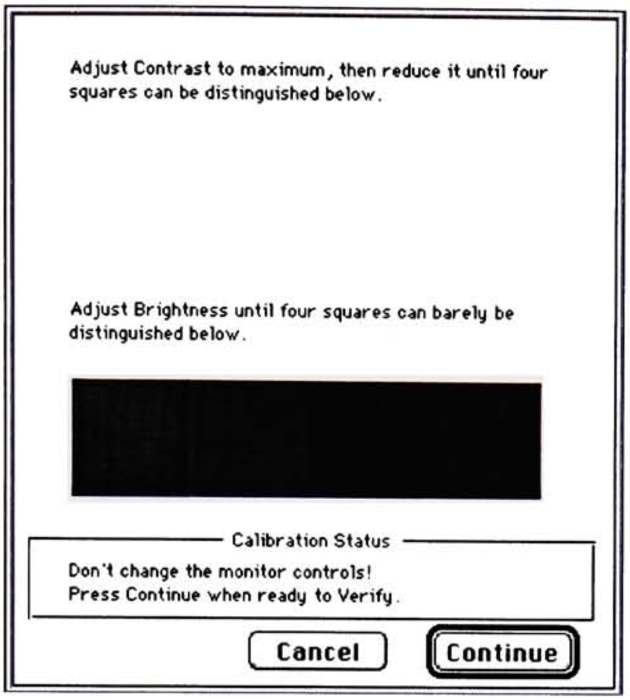


Figure A-5. The Brightness/Contrast setting in ColorTron Calibrator

ColorTron come with a test patch which helps set brightness and contrast (refer to Figure A-5). The user first adjusts the contrast knob to maximum, then reduces it until four squares can be distinguished among four bright patches; the adjustment is to make sure the highlight data will be displayed with highest brightness without losing highlight detail. The user then adjusts the brightness knob until four dark patches can barely be distinguished; the adjustment is to ensure the display of shadow data starting from true black without losing shadow detail.

Both Poynton and ColorTron's goal are to achieve the maximum display range of the CRT. The rule of thumb is to get the brightest white without clipping of high digital count and obtain the true black without clipping on low digital count.

Nevertheless, from Poynton's recommendation, we will sacrifice the maximum display range for a more pleasing appearance because excessive brightness has a number of disadvantages. First, the sensitivity to flicker increases as brightness increases, so setting

the monitor too bright is likely to increase the perception of flicker[1]. Second, a number of phenomena act to scatter light onto the face of the screen; and the higher the brightness of bright areas of the picture, the more light is scattered into the dark areas. This scattered light reduces the contrast ratio of the picture. Third, operation at high brightness tends to defocus the electron beam of the CRT, resulting in poor sharpness.

Poynton has good reason not to set the contrast of CRT to the highest possible intensity. His view does not appear in ColorTron's manual. By following the ColorTron's instruction on contrast and brightness setting, we always get higher intensity than following Poynton's instruction. An example of an Apple 16" Multisync monitor setting by ColorTron's rule results in a maximum intensity of 84.5 (Y) vs. 73.4 by Poynton's rule.

A test of the relationship of CRT maximum intensity and gamma starts with a CRT with maximum intensity of 84.5 by ColorTron's Brightness/Contrast setting and 73.4 by Poynton's setting seen in Table A-1.

The gamma calculated from ColorTron's setting is 1.642; 1.661 from Poynton's setting. (Refer to Appendix B for how to calculate gamma.)

Table A-1. Digital count and luminance reading

Digital Count	Y (ColorTron)	Y(Poynton)
255	84.5	73.4
191	53.2	46.7
127	27.9	23.9
63	8.63	7.35
0	0.13	0.12
Gamma	1.642	1.661

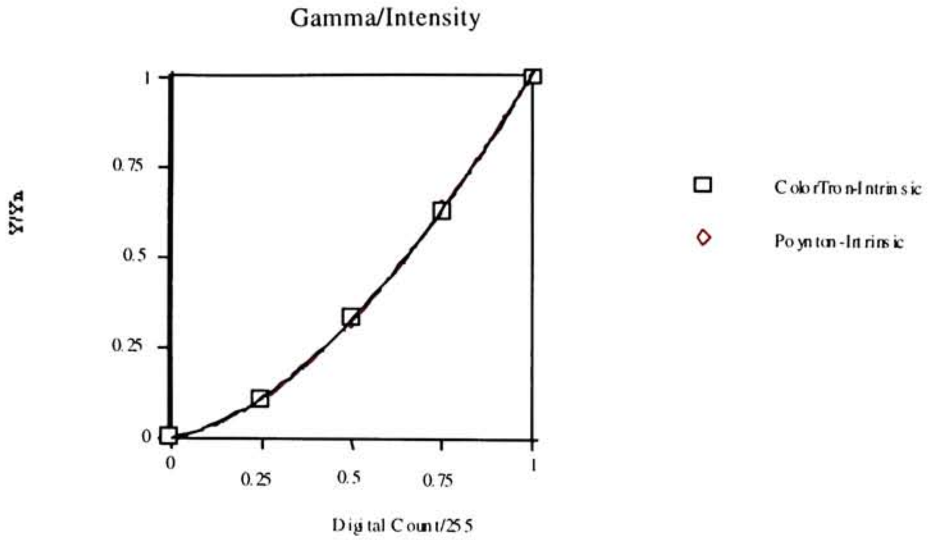


Figure A-6. Gamma from different Contrast/Brightness setting

From Figure A-6 we can see that there is no significant difference in gamma; in this case, the deviation of 10 on intensity (Y) resulted only 0.02 deviation on gamma. It seems that the difference of Y does not have much influence on CRT gamma. From this experiment, it seems that Poynton's rule on Contrast/Brightness setting is more acceptable because it eliminates flickering, light scattering, and defocus problems and yet with no difference on display gamma in comparison with the ColorTron's setting.

The next topic is to examine the difference of gamma after calibration.

Table A-2 is the Digital Count/luminance data after calibration. The gamma calculated from ColorTron's setting after calibration, seen in Figure A-7, is 1.912 and 1.911 from Poynton's setting.

Table A-2 Digital count and luminance reading after calibration

Digital Count	Y(ColorTron)	Y(Poynton)
255	54.5	47.4
191	32.4	27.8
127	14.7	13.2
63	3.9	3.38
0	0.11	0.11
Gamma	1.912	1.911

From Table A-2 we can see the intensity deviation is 7.1 and gamma deviation is only 0.001. It not only shows that the intensity does not have much influence on gamma but also the ColorTron Calibrator has the capability to bring the divergence of hardware performance into the target value.

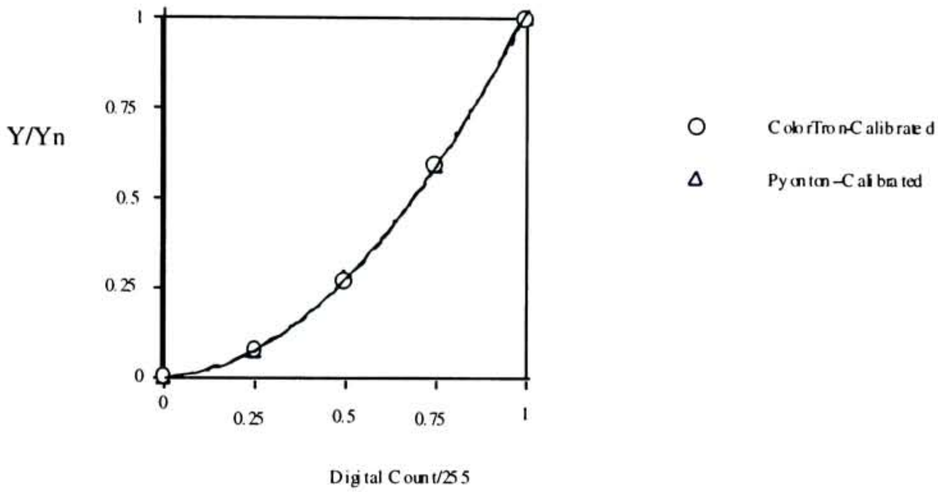


Figure A-7 Gamma from different Contrast/Brightness setting after calibration

It is obvious that after the calibration the intensity of CRT reduces significantly. For ColorTron's setting, the intensity is reduced from 84.5 to 54.3; it is even less than Poynton's setting before calibration (74.5). The reduction of intensity is because the ColorTron Calibrator has to reduce the signal of blue and green electron gun to match the standard white (D50). The reduction on blue channel and green channel is shown in Figure A-8.

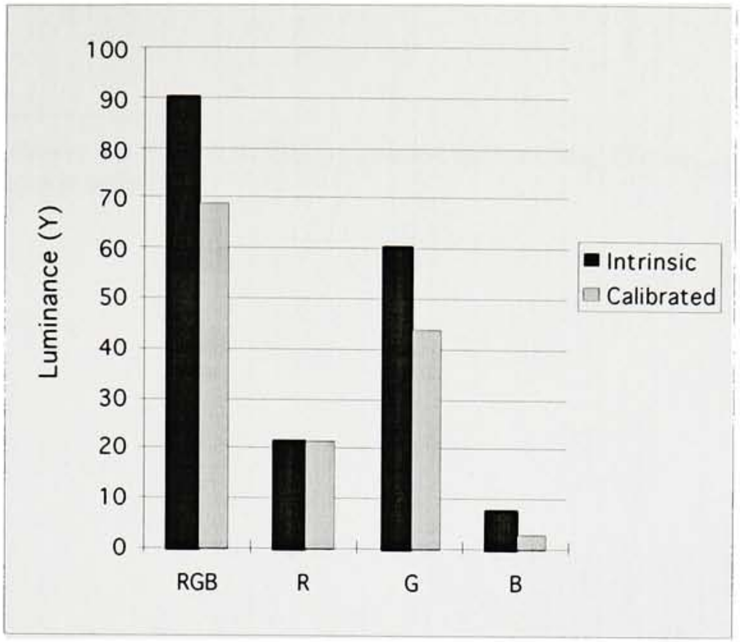


Figure A-8. The intensity of separate channel from intrinsic and calibrated CRT

In this example we can see that in order to bring back the D50 white from a CRT's intrinsic bluish white, we have to reduce about 27% of green intensity and 62% of blue intensity and retain the red intensity to match the D50 white.

Poynton's paper on Contrast/Brightness setting did not mention white point, and since there is no significant different in gamma from the two settings, the CRT calibration procedure will follow ColorTron's instruction in this study.

Another consideration for brightness and contrast setting is the luminance ratio of CRT display. From Table A-3 we can see even the lowest contrast ration (2.63) is still enough to cover the offset printing density range.

Table A-3 Luminance ration of each Brightness/Contrast setting

Intrinsic	Digital count	Y	Calibrated	Digital count	Y
ColorTron	255	84.5	ColorTron	255	54.5
	0	0.13		0	0.11
log Ratio		**2.81**	**log Ratio**		**2.69**
Poynton	255	74.3	Poynton	255	47.4
	0	0.12		0	0.11
log Ratio		**2.79**	**log Ratio**		**2.63**

[1] "Black Level and Picture," by Charles A. Poynton, Online, Internet, May 1996 at http://www.inforamp.net/~poynton.

Appendix B

The Calculation of Gamma

Appendix B

The Calculation of Gamma

Because gamma analyses in this study are based on normalized data, it is possible to see a543.0 different result from other research base on different definition and calculation on gamma. The gamma calculation used in this study describe as follows:

Started from the most simple definition of gamma (γ): Output=Input$^{\gamma}$. To calculate the gamma, simply implement a power fitting curve function between input data and output data.

In an example of calculating the CRT gamma of an Apple 16" MultiSync monitor, display 5 levels of digital count on CRT: O, 63, 128, 191, and 255; and then measure its luminance response by Minolta CA- 100.

The result is shown as follow:

Digital Count	
255	69.1
191	40.6
127	19.2
63	5.11
0	0.1

All the digital count and luminance data normalize as

$$x_n = \frac{x - x_{mim}}{x_{\max} - x_{\min}}$$

Where xn is normalize data, xmax is the maximum data, and xmjn is minimum data.

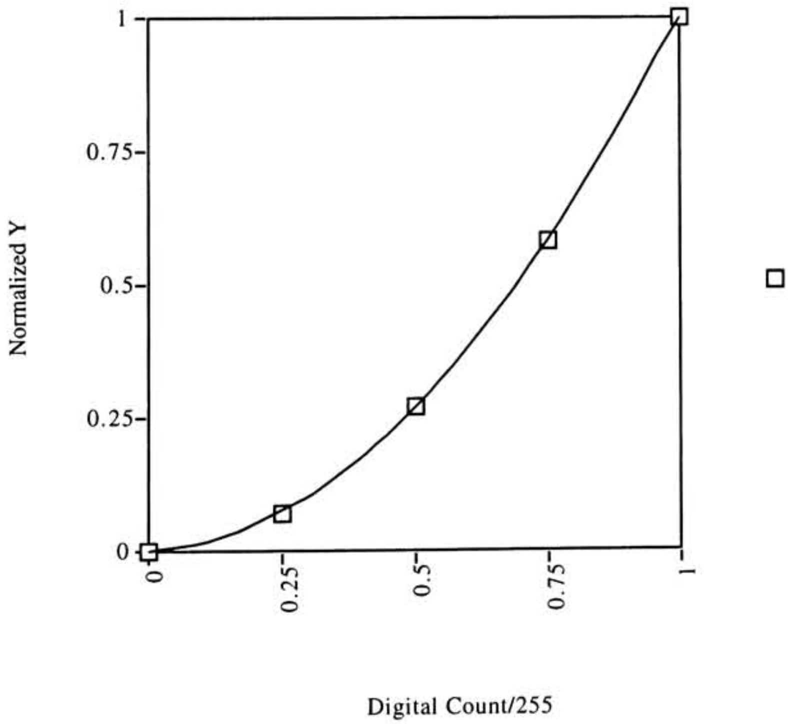
After normalizing the data, the result shows:

Digital Count/255	Y/Yn
1	1
0.75	0.58
0.5	0.27
0.25	0.07
0	0

Plot the scatter plot chart from above data and then apply the power curve fitting. We can obtain an equation shown as follow. The raised power number, 1.918 in this curve, is the CRT gamma.

$y = 1.007x^{1.918}$ $r^2 = 1.000$

CRT-3 (Uncalibrated, γ)



Appendix C

Data of Observer Experiment

Appendix C

Data of observer experiment

Table C-1 The non-triads samples of three musicians image

Ranks	three musicians/ Dark						
Judges	Pic.1	Pic.2	Pic.3	Pic.4	Pic.5	Pic.6	
1	2	1	6	3	5	4	
2	2	1	5	3	6	4	
3	4	1	6	2	5	3	
4	2	1	5	3	6	4	
5	2	1	5	3	6	4	
6	2	1	5	3	6	4	
7	2	1	5	4	6	3	
Ave.	***2***	***1***	***5***	***3***	***6***	***4***	
Sum	16	7	37	21	40	26	
Avera	24.5	24.5	24.5	24.5	24.5	24.5	
Sum-	-8.5	-18	12.5	-3.5	15.5	1.5	
Square	72.3	306	156	12.3	240	2.25	**790**
Coefficient of concordance							**0.92**

Table C-2 Non-triads samples of Orchid image

Ranks	Orchid/ Dark						
Judges	Pic.1	Pic.2	Pic.3	Pic.4	Pic.5	Pic.6	
1	4	2	6	3	5	1	
2	6	3	5	2	4	1	
3	6	1	5	3	4	2	
4	6	3	5	2	4	1	
5	6	1	5	3	4	2	
6	5	3	6	2	4	1	
7	5	3	4	1	6	2	
Ave.	***6***	***2***	***5***	***3***	***4***	***1***	
Sum	38	16	36	16	31	10	
Avera	24.5	24.5	24.5	24.5	24.5	24.5	
Sum-	13.5	-8.5	11.5	-8.5	6.5	-15	
Square	182	72.3	132	72.3	42.3	210	**712**
Coefficient of concordance							**0.83**

Profile 1= Gamma 1.8, White point D50
Profile 2= Gamma 1.8, White point D65
Profile 3= Gamma 2.15, White point D50
Profile 4= Gamma 2.15, White point D65
Profile 5= Gamma 2.4, White point D50
Profile 6= Gamma 2.4, White point D65

In Table C-1, the three musicians' images evaluated under the dark ambient, there are 7 non-triads' samples collected out of 10 observers. From the calculation according to

Al Rickmers's "Subjective Color Evaluation Using Paired Comparison," the sum of square is 790; which is greater than the critical value displayed at Table C-3 (335.2). The agreement among judges is consistent at the 95% of confidence level. The coefficient of concordance is 0.92 according to the equation (1).

Table C-3 The critical values for significance of agreement among judges, 0.05 level of significance.

Number of Pictures	Numbers of Judges (J)			
	4	5	6	7
3	---	64.4	103.9	157.3
4	49.5	88.4	143.3	217.0
5	62.6	112.3	182.4	276.2
6	75.7	136.1	221.4	335.2

$$W = \frac{12(S)}{J^2 P(P^2 - 1)}$$ Equation (1)

where J= number of Judges

P= number of Prints (P=6) S= Sum of squares from Table

In the Table C-2, theorchid image evaluated under the dark ambient, there are 7 non-triads samples out of 10 observers. The sum of square is 712, which is greater than the critical value (335.2); the agreement among judges is consistent. The coefficient of concordance is 0.83.