EXPERIMENTAL DETERMINATION OF A DEVICE INDEPENDENT COLOR REPRODUCTION ALGORITHM

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ABSTRACT

The color reproduction algorithm is an often ignored aspect of device-independent color systems. This algorithm is responsible for good tone and color reproduction of both reproducible and non-reproducible colors. An algorithm of this type was obtained empirically. A hue circle test object was reproduced on a rotary drum scanner and the CIELAB values of the reproduction were plotted against the CIELAB values of the original so that a color reproduction algorithm (for reproducible colors) was created.

This approach proved to be a success as a linear trend was noticed in all the graphs. These graphs also suggest that the highlight has been faithfully reproduced and that gray balance has been maintained. The success of the results permitted equations to be created which, when used in conjunction with one another, constitute a color reproduction algorithm for a device-independent system.

The color reproduction algorithm under the conditions of the experiment can be summarized as follows: Linear compression is performed on L^* a^* and b^*; subject to constraints to maintain highlight integrity and gray balance.

INTRODUCTION

BACKGROUND

Modern technology is constantly creating new demands for the printing industry. For example, a printer may have to reproduce an image that was sent to him in the form of film, satellite links, or

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telecommunication. Furthermore, the same image may be sent to the printer in various forms, and the customer will expect identical reproductions. In addition, the customer may require identical reproductions of the image by various output systems such as a soft proof or a hard proof.

In order to perform these tasks, the printer must use a device-independent color system rather than a device-dependent color system. Device-independent color means representations based on human color vision, as opposed to device-dependent color representations such as ink dot percentages [1]. The main advantage of using this type of system is that it can be interfaced with many different input data color sources as well as many output devices. Other advantages of this system are that:

1. It uses a standard and internationally accepted method for specification of color [2].

2. It separates the editorial functions provided to the user and the reproduction processes themselves. Which means that the user only has to be concerned with how to make the input image pleasing while the system worries about the details of how to reproduce an image on the desired output device [3]. Since the operators work with color rather than colorant, relatively little specialized knowledge of the output device or medium is required and they become productive with the system quickly [4].

3. The scanner of this system is intended to be a tristimulus colorimeter. The most important advantage of this is that a color is metameric to the scanner if and only if it is metameric to a human [4].

All of these advantages give the printer the versatility needed to compete in today's market.

> Device-independence means dependence on an ideal or universal device, which provides the reference coordinate system used to represent an image. Device-independent color is based on a human color vision model, formalized by the CIE system of colorimetry: the

> ideal device is the CIE Standard Observer and the reference coordinates are XYZ tristimulus values (or a transformation of them). XYZ values can be computed from the spectral energy distribution of a color stimulus or measured directly using a colorimeter [1].

A limitation encountered by printers is that conventional color electronic prepress systems (CEPS) can not create device-independent representations. However, a new type of CEPS has been developed that is based on the principles of colorimetry. One such system is the EIKONIX Designmaster 8000 [2].

The idea of systems like the Designmaster is that the representation of stored images is in the coordinates of an approximately uniform color space (UCS) such as CIELAB. By doing this, the system becomes device independent. That is, the system can be easily interfaced to any source of input color data (scanners, satellites, telecommunication) or output devices (scanners, ink jet plotters, CRTs) providing that the appropriate math modeling and color reproduction algorithms are used. The following flowchart illustrates the steps performed in a device-independent CEPS [5,6].

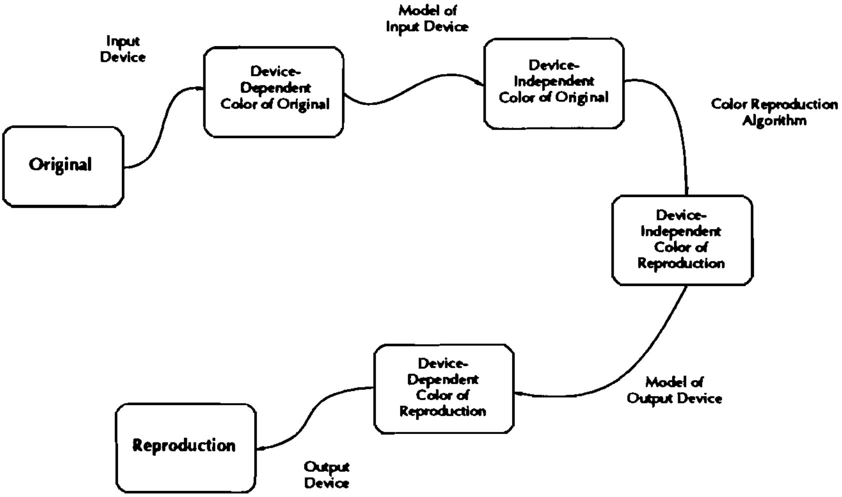

Figure 1.
Data Flow Diagram for a CEPS using Device-Independent Color.

An often ignored aspect of device-independent color is the need for the color reproduction algorithm. Often, it seems, it is assumed that the color of the reproduction matches that of the original. This is not usually possible because of reasons which will be discussed later.

The color reproduction algorithm consists of two components which are:

1. Reproduction of reproducible colors
2. Reproduction of nonreproducible colors

This paper will discuss only this first point. The reproduction of nonreproducible colors is beyond the scope of the present work. The algorithm is responsible for good tone and color reproduction.

Basic requirements of good tone reproduction include [5]:

1. The highlight of the reproduction should correspond to the highlight of the original.
2. The shadow of the reproduction should correspond to the shadow of the original.
3. A plot of L* of the reproduction vs. L* of the original should be linear in a uniform visual scale for "normal" originals.

Basic requirements of good color reproduction also include [5]:

4. Grays should be reproduced as grays.
5. Hues should be faithfully reproduced.

These requirements impose constraints on the relationships between the UCS values of the original and the reproduction. Because of highlight requirements a plot of L* of the reproduction vs. L* of the original should go through point (100,100). Because of gray balance requirements a plot of a* of the reproduction vs. a* of the original should go through point (0,0). For the same reason a plot of b* of the reproduction vs. b* of the original should go through point (0,0).

PROBLEM

Looking at the previous diagram one can see that the color reproduction algorithm is an essential step in a device-independent CEPS. The algorithm is used to transform the UCS values of the original into UCS values of the reproduction.

Tone and gamut compression are problems a color scanner encounters when reproducing transparencies or reflection images into halftone film separations for offset printing.

Tone compression is required because offset printing is capable of producing maximum densities of 2.0 or lower whereas an original image may contain densities greater than 2.0. The original image may contain colors which require dot percentages of zero or less, or 100 and greater in order to be reproduced. However, it is impossible to create dot percentages of this type therefore these colors are out of gamut and are unprintable. Such colors must be compressed in order to be reproduced although they will not look exactly like the original image.

William F. Schreiber of MIT, one of the pioneers of device-independent systems suggests that the function of tone and gamut compression be performed with close operator involvement, rather than automatically for this system. He states that "It is just because the output usually has a much smaller gamut, especially in the case of transparencies, that the input must be altered, and usually this cannot be done automatically by any known algorithm" [7]. However, it is the objective of this experiment to create a color reproduction algorithm for such a system.

APPROACH

Conventional rotary drum scanners produce high quality color reproductions which the printing industry considers as the reference standard. Therefore, the tone and gamut compression algorithm used in such a scanner is widely accepted. A similar algorithm can be created for a device-independent system by using the following approach.

The same image, in both transparency and reflection form would be reproduced by a rotary drum scanner. The separations produced by this scanner would be used to make hard proofs. Using a spectrocolorimeter, CIELAB measurements would be taken from the same areas of the originals and the reproductions. A computer would then be used to create graphs for L^* a^* b^* values plotting the original against the reproduction. Regressions would then be run on the L^* a^* b^* values to force them through certain points on the graph. A color reproduction algorithm could be created based on the relationships implied in these plots.

A similar approach was performed in 1971 by Pobboravsky, Pearson, and Yule of RIT. They used a converted densitometer as their colorimeter, and a modified Adams Chromatic Value color space. The 1971 report concluded that "a good color scale and hue circle test object ... would be needed in investigating the subject more deeply" [8]. In addition, improvements in not only color reproduction in general, but also in the following have been made in the last 20 years:

- Color separation systems (especially scanners)
- Color proofing systems
- Color measurement instruments

Advantage was taken of all these improvements for this investigation by using the following.

- Improved color scanner (Royal Zenith 210L)
- Improved proofing system (3M Matchprint II)
- Improved color measuring instrument (Gretag SPM 100)
- Improved color space (CIELAB)
- Hue circle test object (Kodak Q60 Targets)

The Kodak Q60 targets were selected because they are hue circle test objects, and are an emerging de facto standard.

The Q60 targets consist of 236 patches. A 20 step grayscale appears along the bottom of the target. The rest of the target is composed of 19 columns, each containing 12 patches. All of the Q60 targets contain the same image, but that image is reproduced on various substrates. The Q60 targets contain both reproducible and nonreproducible colors. However, this paper excludes the nonreproducible colors because they are beyond the scope of this experiment.

METHODOLOGY

IMAGE

The images used for this experiment were the color charts of the Kodak Color Reproduction Guide. The Kodachrome Q60B was selected for the transparency, and the Ektacolor Plus Q60C was used for the reflection image.

SCANNING

A Royal Zenith 210L rotary drum scanner was used to make the separations. The following setup was used for this scanner.

1. A 150 line screen, square dot shape, and positive separations were selected.
2. A complete linearization was performed.
3. The grayscale on these images was used for the setup.
   Step 1 - Highlight placement, Step 11 - Midtone placement, Step 20 - Shadow placement
4. Selective color correction was performed by an experienced scanner operator to achieve desirable dot percentages.
5. Magnification: Q60B - 261%, Q60C - 138%
   These percentages were used so both images would be reproduced as the same size, using as much of the film as possible.
6. Film: Dupont Chronascan Argon Ion Laser Scanning Film
7. Processor: Fuji rapid access

PROOFING

A 3M Matchprint II Positive proofing system was used, and a commercial base was selected. The color sequence used for producing the proofs was MYCK, the standard sequence used at the RIT Proofing Laboratory.

MEASUREMENT

After the proofs were made, all of the patches including the grayscale were measured on all four images using a Gretag SPM 100 spectrophotometer in the colorimeter mode. The colorimeter was setup using a D50 illuminant and a 2° observation angle. The Gretag was connected to a computer so after each measurement was taken it was sent to the computer and stored on a floppy disk.

In order to be measured, the Q60B original was placed on top of an overhead projector, and the lamp inside the Gretag was removed. An overhead projector using a tungsten filament light source was used because of its constant output. A fluorescent transillumination source was originally used, but was rejected because of flicker. A voltage stabilizing transformer was connected to the projector to further ensure light output consistency. A specific location on the projector was used to take all measurements to aid in consistent results. After the Q60B original was measured, the lamp for the Gretag was replaced and the reflection images were measured.

For the three reflection images the Gretag was calibrated using the supplied reference white calibration plaque, and the grayscale was measured. The Gretag was calibrated on the overhead projector for use with the Q60B. The patches on both proofs and the Q60C were measured at 10 second intervals to ensure consistent output of the lamp inside the Gretag. It was recommended that all images be measured in xyY values in order to make measurements relative to the film base plus fog using a von Kreiss type adaptation. The xyY values were then transformed into CIELAB values using equations which are included in the appendix of this paper [9].

GRAPHING

After all measurements of the images were taken, the values were stored on spreadsheet software. The reproducible colors were separated from the nonreproducible colors by using a list supplied by Jeffrey Wang of the RIT Research Corporation. Graphs of the reproducible colors were then made by plotting the original against the reproduction in L^* a^* b^* values.

When viewing all the graphs a linear trend was noticed. A regression formula was then used to force certain L^* a^* b^*, values through certain points to create the slope. L^* was forced to go through point (100,100) in order to achieve good highlight reproduction whereas a^* and b^* were forced to go through point (0,0) in order to achieve good gray balance. The reason for doing this is that good tone and color reproduction depend on certain values to be located at these points. After the slope was created the regression line was superimposed on the graphs. The regression formulas used to create the slopes are included in the appendix of this paper [10].

RESULTS

The following graphs were created using the previously explained methodology.

When viewing the graphs one sees that the trend is linear. Some deviations are noticed in the L* graphs; this can be attributed to the setup of the scanner such as quartertone placement. Scatter is also noticed on the a* and b* graphs; this results from the Royal Zenith 210L not being a scanning tristimulus colorimeter. Neither the graphs nor the regressions used were accurate enough to model the scanner; however this was not the purpose. The purpose of this experiment was to get an idea of the color reproduction algorithm implied in the scanner, and this has been done successfully.

Based on the slope of the graphs created using regression the following equations have been created. These equations can be used in conjunction with one another as a color reproduction algorithm for a device-independent system.

Q60B

L^* reproduction = 0.8004 L^* original + 19.96
a^* reproduction = 0.6934 a^* original
b^* reproduction = 0.6754 b^* original

Q60C

L^* reproduction = 0.8250 L^* original + 17.50
a^* reproduction = 0.9316 a^* original
b^* reproduction = 0.7762 b^* original

CONCLUSIONS

Based on the empirical results, the scanner algorithm seemed to suggest itself. Therefore it was possible to create a color reproduction algorithm. The trend of the CIELAB graphs is linear, as is the tone reproduction in L*. The fact that regression was used to force the line

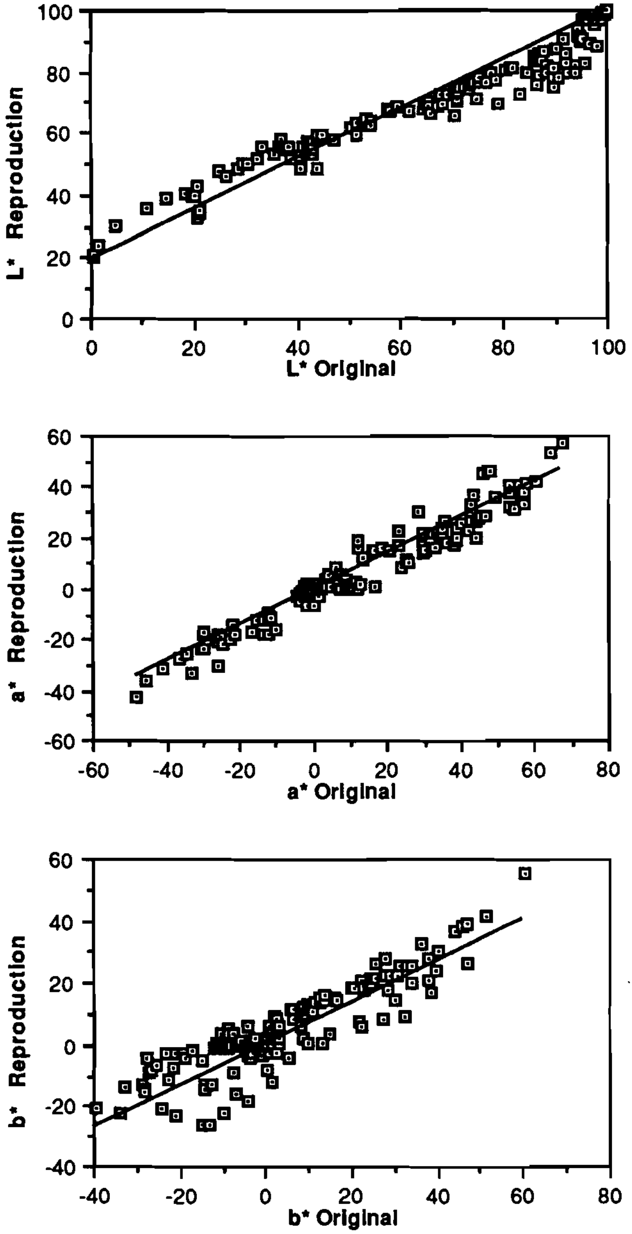

Figure 2.
CIELAB values of the Reproduction vs Original, for Q60B.
(a) for L* (b) for a* (c) for b*.

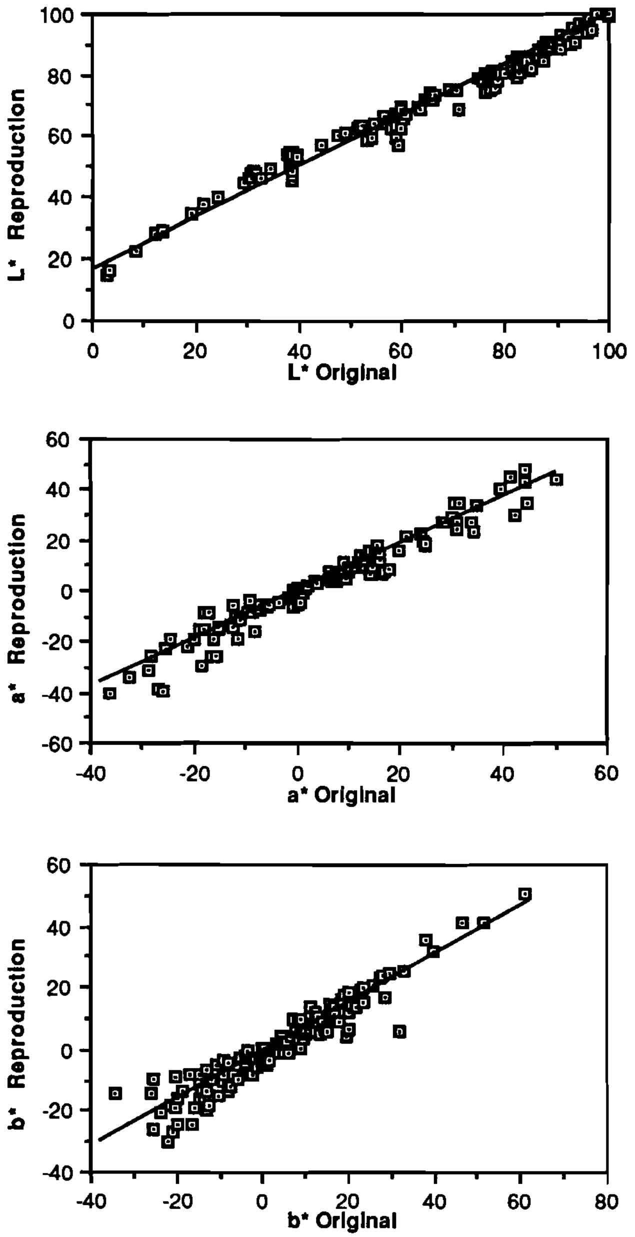

Figure 3.
CIELAB values of the Reproduction vs Original, for Q60C.
(a) for L* (b) for a* (c) for b*.

through certain points did not distort the graphs, or give false data because values appeared very close to these required points. The regression line of the L* plots crosses through point (100,100) which suggests that the highlight has been faithfully reproduced. Therefore good tone reproduction has been achieved. The regression line of the a* and b* plots crosses through point (0,0) which suggests that grays will reproduce as grays. Therefore good color reproduction has been achieved as well. The slope for all graphs is less then 1, as should it be when compressing the tonal and gamut range of the original.

Because of tone compression requirements CIELAB values of a reproduction will not be the same as the CIELAB values of an original, therefore using ΔE* as a criterion for evaluating the validity of this experiment is not applicable.

Although neither the graphs nor the regressions were accurate enough to model the scanner they were accurate enough to get an idea of the color reproduction algorithm implied in the scanner, which was the intent of the experiment. Some deviations are noticed in the L* graphs, this is not a fault of the experiment but is caused by setup of the scanner. In addition, some scatter is noticed in the a* and b* graphs; this problem is due to the fact that the Royal Zenith 210L is not a scanning tristimulus colorimeter. A rotary drum scanner's algorithm was modeled in an attempt to create an algorithm for a device-independent system. This does not mean that the algorithm created by this experiment is accurate enough to be used in a rotary drum scanner for such a system. Instead, this investigation reveals the basic relationships implied in a device-independent color reproduction algorithm, and shows that such an algorithm can be experimentally determined.

ACKNOWLEDGMENTS

The author would like to acknowledge the following people, without their help this report could not have been completed.

J. A. Stephen Viggiano of the RIT Research Corporation for suggestion of the research topic, and for help in performing this experiment.

Kelly Laughlin of the RIT School of Printing Management and Sciences for his help in producing the color separations.

Jeffrey Wang of the RIT Research Corporation for supplying a list of reproducible colors on the Q60 targets.

Burt Saunders of the RIT Research Corporation who explained what device-independent systems are and how they work.

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APPENDIX

Equations used in this Investigation

Equations used to transform xyY values into CIELAB values:

$$X = x \frac{Y}{y}$$
$$Z = (1-x-y) \frac{Y}{y}$$

$$f(u) = \begin{cases} u^{1/3}, & \text{if } u > \left(\frac{6}{29}\right)^3 \\ \frac{1}{116}\left(\frac{29}{3}\right)^3 u + \frac{4}{29}, & \text{if } u \leq \left(\frac{6}{29}\right)^3 \end{cases}$$

$$L^* = 116\, f\left(\frac{Y}{Yn}\right) - 16$$

$$a^* = 500\left[f\left(\frac{X}{Xn}\right) - f\left(\frac{Y}{Yn}\right)\right]$$

$$b^* = 200\left[f\left(\frac{Y}{Yn}\right) - f\left(\frac{Z}{Zn}\right)\right]$$

where Xn, Yn, and Zn are the tristimulus values of the highlight.

Regression formulas used to calculate the slopes of the graphs:

$$\text{Slope for } L^* = \frac{\sum (100 - L^*_o) \bullet (100 - L^*_r)}{\sum (100 - L^*_o)^2}$$

$$\text{Slope for } a^* = \frac{\sum a^*_o \bullet a^*_r}{\sum a^{*2}_o}$$

$$\text{Slope for } b^* = \frac{\sum b^*_o \bullet b^*_r}{\sum b^{*2}_o}$$

where L^*_o, a^*_o, and b^*_o are the CIELAB values of the original, and L^*_r, a^*_r, and b^*_r are the CIELAB values of the reproduction.

$$\text{Intercept for } L^* = 100 \bullet (1 - \text{Slope for } L^*)$$