การแปลงค่าสีจากระบบสี RGB เป็น CMYK โดยใช้สมการเชิงเส้น
ร่วมกับ LUT ของแม่พิมพ์ดำ

นาย กฤษดา กิตติสาระกุลชัย

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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RGB TO CMYK COLOR TRANSFORMATIONS USING COMBINATION OF LINEAR FUNCTION AND BLACK PRINTER LOOK-UP TABLE

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งานวิจัยนี้ศึกษาการแปลงค่าสีจากระบบสี RGB ไปเป็นระบบสี CMYK โดยการแบ่งการแปลงค่าสีออกเป็น สองขั้นตอน คือ การแปลงค่าสีจากระบบ RGB ไปเป็นค่าสีในระบบ CMY โดยใช้สมการเชิงเส้น และ แปลงค่าสีจากระบบ CMY ไปเป็นค่าสีในระบบ CMYK อีกขั้นหนึ่ง โดยการใช้ตารางเทียบค่าสี LUT ของแม่พิมพ์ดำ พบว่า การใช้หลักการของทฤษฎีสีแบบลบ และสมการฟังก์ชั่นแบบไม่เชิงเส้นมิติเดียวระหว่างคู่สีตรงข้าม จะ ช่วยทำให้การแปลงค่าสีจากระบบ RGB ไปเป็นระบบสี CMY แบบเชิงเส้น ทำได้ง่ายและถูกต้องมากขึ้น และความแม่นยำจะเพิ่มขึ้นเมื่อเพิ่มจำนวนของสัมประสิทธิ์ในสมการเชิงเส้นที่ใช้แปลงค่า พบว่า สำหรับตารางเทียบค่าสี LUT เป็นตารางแบบมิติเดียว และใช้การคำนวณด้วยวิธีเฉลี่ยค่า(Bilinear Interpolation) จากผลการศึกษาการแปลงค่าสีด้วยวิธีนี้ ค่าความแตกต่างสีที่ได้จะไม่สูงมากนักคือ ระหว่าง 9-15 ซึ่งแสดงให้เห็นว่า มีความเป็นไปได้ ในการใช้ข้อมูลสี CMYK แทน CMY เพราะมีข้อดีหลายประการ เช่น การประหยัดหมึกพิมพ์สี และมีความสมดุลของสีเทาของภาพดีขึ้น เป็นต้น

ภาควิชา วิทยาศาสตร์ทางภาพถ่ายและเทคโนโลยีทางการพิมพ์ ลายมือชื่อนิสิต K. Kitisarakulchai

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ปีการศึกษา 2542 ลายมือชื่ออาจารย์ที่ปรึกษาร่วม ....

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KEY WORD : RGB/CMY/CMYK/COLOR TRANSFORMATION/COLOR CONVERSION/LINEAR TRANSFORM/REGRESSION/METRIC TRANSFORM/LOOK UP TABLE/LUT/BLACK PRINTER
KRISADA KITISARAGULCHAI: RGB TO CMYK COLOR TRANSFORMATION USING COMBINATION OF LINEAR TRANSFORMATION AND BLACK PRINTER LUT
THESIS ADVISOR: ASSOC. PROF. ARAN HANSUESAI, PH.D.

This reseach is attempted to study the method of RGB to CMYK color transformation. There are 2 steps; the linear transformation of RGB to CMY and the transformation of CMY to CMYK through Black printer LUT. It is found that the cooperation with theoretical subtractive color definition, one dimension non-linear function between opposite colors, and the linear transformation RGB to CMY is possible. The accuracy depends on the number of coefficients of the linear function. The LUT is defined by one dimension Bilinear Interpolation.

The comparison of the obtained color differences, resulted from the output data CMY and CMYK, seem to be close to one another, ranging from 9 to 15. It implies that this transformation process can be used to output CMYK in stead of CMY, as the benefit is the reduction the amount of color inks and the improvement of gray balance.

ภาควิชา วิทยาศาสตร์ทางภาพถ่ายและเทคโนโลยีทางการพิมพ์ ลายมือชื่อนิสิต..

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Krisada Kitisaragulchai

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CHAPTER 1

INTRODUCTION

1.1 Scientific Rational

The digital printing process starts with a CMY representation of the original object on film. The CMY image is scanned by a scanner or taken by a digital camera and spends a short part of life as an RGB file. The RGB file is range compressed and masked and its transfer curve is shaped to produce a final CMYK ready for printing.[(1)]

In color reproduction, there are two kinds of important devices, input and output devices. The input devices, such as color scanner or digital cameras, are used for taking images of originals, normally use RGB color space. On the other hand, output device, such as color printers, imagesetters or color proffers, are used for printing out the original copies of the images, mostly use CMY or CMYK color space. It cannot be avoided using color transformation between RGB to CMY or CMYK in the color reproduction.

Color transformation that uses in ordinary color image equipment that has reasonable price often use simple but incorrect transformations. These methods cause color production from the equipment different too much in color while complicated and accurate color transformation is always found in more expensive equipment.

In the past, athough, the expensive equipment used color transformation of RGB to CMYK. It still could be adjusted the color correction by an experienced user that cannot obtain constant result of the reproduction. Recent idea, it can be achieved by using the standardized color value to do color transformation that obtains a more consistent result.

Color transformation can be applied to restore of faded color images[2],[3] or motion picture[4].

1.2 Objectives

The objectives of this research are as follows:

1.2.1 To finds alternate method of color transformations from RGB to CMYK systems to be more precise and appropriate as assigned.

1.2.2 To adopts new methods using the Black printer Look-up table instead of using UCR and GCR.

1.2.3 To be the way to control color images production involving with color images that have different color systems to make the difference of color presented in limited areas.

1.3 Scope of the research

The research involves a method of color transformation of the color in the RGB system to CMYK. Color transformation of RGB to CMY is achieved by doing gamma correction of RGB. Using SPSS software to find the coefficient of the relation uses the method of linear transformation. The coefficient is calculated from the standardized data of the IT8 with its color test chart. The black printer look-up table is created for calculating the color amount of the black ink. It is used for transforming CMY to CMYK. The color evaluated by the color difference of the IT8, color test chart and its image that print out from the printer using the transformation.

1.4 Content of the Thesis

This thesis consists of 5 chapters including (1) introduction, (2) theory and literature review, (3) experimental, (4) results and discussion, and (5) conclusion and suggestions. Chapter 2 presents color model or color space, color mixing, and color transformation techniques. Chapter 3 discusses the details in the materials, apparatus, and the procedure of this research. Chapter 4 explains the detail of the proposed transformation process. Finally, chapter 5 is the conclusion and suggestion on the research.

CHAPTER 2

THEORY AND LITERATURE REVIEW

2.1 Theoretical considerations

2.1.1 *Specification of Color*

Human interest in color images goes back to the Lascaux caves (about 25,000 BC) in northern Spain and southern France. Here the cave artists used oxides of iron for red, oxides of manganese for blue-black and dark brown, and iron carbonate for yellow. Painted images have accompanied human activities throughout history[6].

When we communicate color, we normally call color by name such as red, green, blue that refers to hue, whereas saturation like "muted," "pastel" or "bright" are added to emphasize communication[5]. These basic hue names and their descriptors help communicate relatively specific color perceptions. However, when different light sources are used with difference people (observers), color names are inappropriate for objective specification. They also deal to their inherent ambiguity. For example, green can refer to emerald green, army green, or lime green. Each of us may have an image of army or lime green, but the image of their exact value varies from one person to the next. Furthermore, when we want to communicate a slightly difference lime green, color names system is not precise enough for communicating. Color specification and color measurement are, now, necessary. The color occurs when a light emits from a light source strike an object and reflect difference mixture of colors that have not been absorbed by the object surface to our eyes. It is hard to measure color by this meaning because it hard to directly measure nerve impulse of the observer when the color of light reach our retina. We can measure the physics properties of the light that come from the object that we want to measure color. Physical measurements reveal aspects of colors not immediately obvious to the eye. White is actually composed of many different wavelengths or that very colorful objects, like a banana or tomato, reflects a wide range of wavelengths. Dramatically different combinations of wavelengths can produce the same color sensations. We cannot directly perceive these aspects of color, nor are they intuitively obvious. To measure the color, we have to know the relationship between the physical and the perceptual aspects of color to help us aid in the prediction of its appearance and reliable reproduction.

2.1.2 *Colorimetric Systems*

There are many problems on communicating color by color names system rather than using numeric systems that specify mathematical relations between radiant energy entering the eye and colors we perceive. They are called colorimetric systems. Ideally, all colors that appear identical (despite any physical differences) should have the same numeric specification. Colors that have the same numeric specification (even if produced on different devices) should look the same. To find out the color mixture that matches to the sample color is called Color matching.

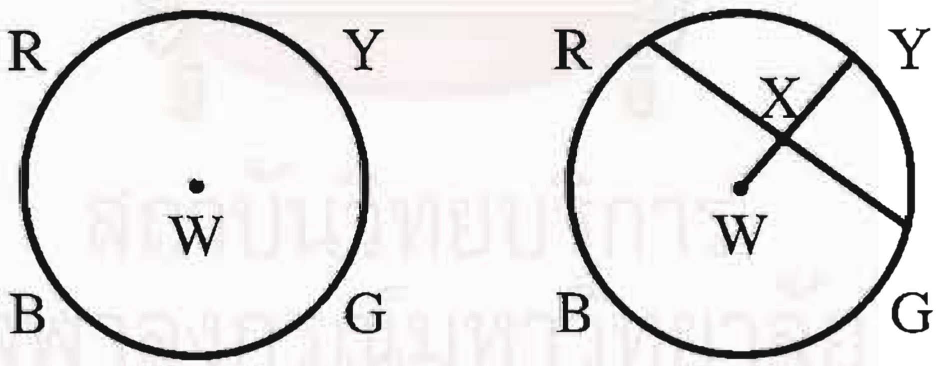
2.1.3 *Color Model or spaces*

There are many types of color spaces. Each type of them created to serve different purposes. They vary in their coordinate system (or axes), scaling and, as consequence, their shapes.

2.1.3.1 Newton's color spaces

The first color space we known were developed by Isaac Newton. He used simple equipment consistent of a few glass prisms and the light from his window at Cambridge University to conducted his color matching experiments. Newton mixed a white light with a yellow light and adjusted another side of color by mixing a red and green light to match each other, pale yellow. Newton explained his observation by positioning the colors of the spectrum on a circle that, he called Hue circle. He explained how the mass at the color's position on the circle represented the intensity of each color. With this simple diagram, he showed how the ratio of red and green intensities matched the addition of yellow and white intensities. The pale yellow color from either combination of color pairs was in the same location. In fact, there were many different color pairs that, when one member was combined with another, produced identical color mixtures.

Thus, even in this early color model, three numbers were necessary: two numbers to specify the center of mass and one to show the sum of the masses (representing their intensity).



$$\frac{WX}{XY} = \frac{RX}{XG}$$

Figure 2-1 Newton's Color Model or Newton's hue circle.

Evolution of Perceptual Color Spaces was started from Newton's color circle then many spaces have been quoted on the same age of time. Most of them generally are easy geometric shape such as color circle of newton's, Runge's doublepyramid, one of the earliest three-dimensional spaces, and the cubic octahedron of the Optical Society of America's Uniform Color Scale.

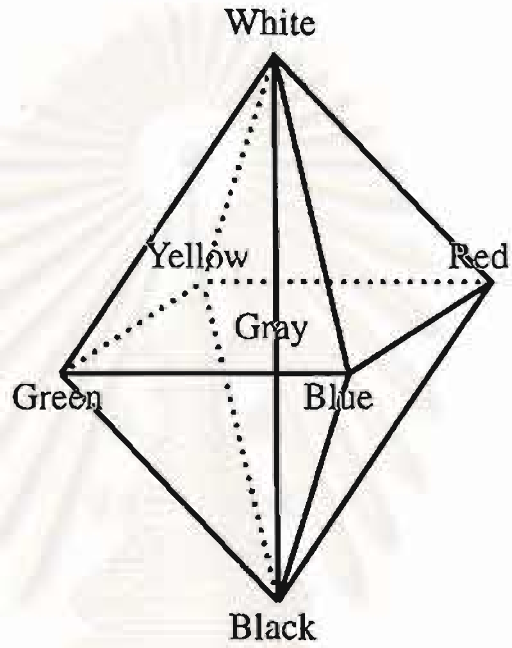


Figure 2-2 Runge's doublepyramid, one of the earliest three-dimensional spaces

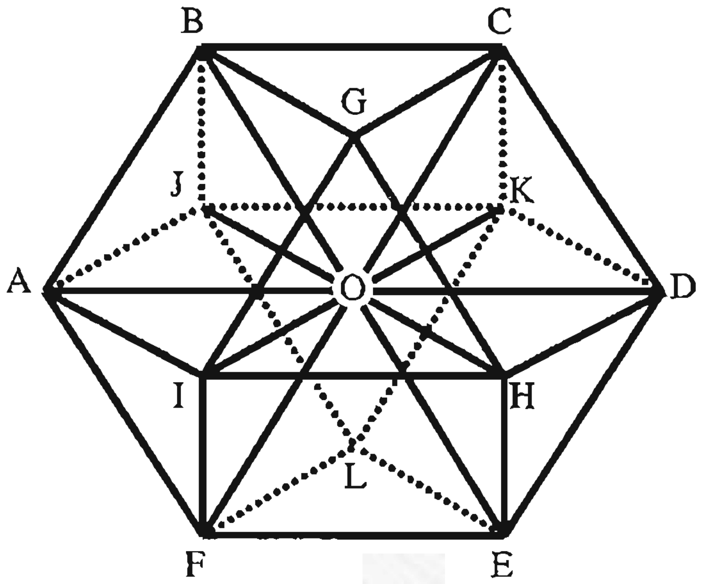


Figure 2-3 T he cubic Octahedron or Rhombohedral of the Optical Society of America's Uniform Color Scale.

2.1.3.2 HSV Color model.

One model used in the graphic arts industry to describe color is called HSV (hue, saturation, and value).

Hue is the property of color that is determined by the wavelengths of light coming from an object. It is the property we refer to when we call a color by its name, such as red, purple, or bluish green.

Saturation, also called color intensity or chromes, is the clarity of a color, the extent to which it is not dulled or grayed.

Value, also referred to as brightness or lightness, indicates how light or dark a color is, how close it is to white or black. Value is the property that determines, for example, whether a color is a light pink or a reddish black. The lightness is also the strength or amplitude of the light stimulating the cones, within our eye's retina. The amplitude of the light increases with stronger light and decreases with weakening light.

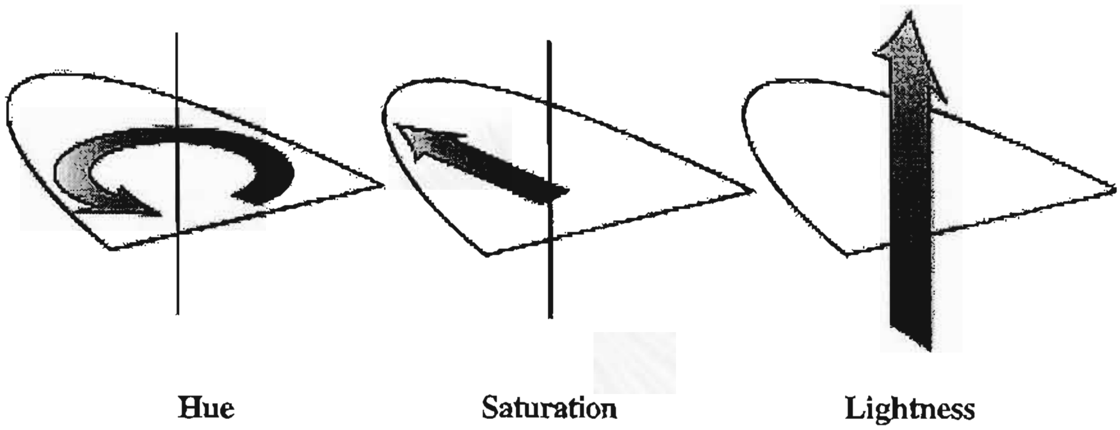


Figure 2-4 HSV, HSL, or HVC color space

The terms used most frequently for these three factors are HSV, HSL (hue, saturation, lightness), and HVC (hue, value, and chrome). These characteristics can be illustrated by a three-dimensional model consisting of stacked "disks." Circular movement around each disk varies the hue. Upward movement from one disk to another increases the lightness.

Radial movement from the center of each disk outwards increases saturation. The model is irregularly shaped because the eye is more sensitive to some colors than others.

2.1.3.3 Munsell

Perceptual color spaces such as Munsell is based on color vision data and experiments. The Munsell color notation system is the basis for the color naming system of the National Bureau of Standard. The numeric values of its colors are direct result of their lightness, hue and saturation. The colors are arranged in a circle in the following order[8]:

Red (R)

Red-purple(RP)

Purple(P)

Purple-Blue(PB)

Blue(B)

Blue-Green(BG)

Green(G)

Green-Yellow(GY)

Yellow(Y)

Yellow-Red(YR)

2.1.3.4 Computer color spaces

Computer color spaces such as RGB is used for software and hardware specification and control of color. RGB space is not based on the visual perception of color but refers to direct hardware control of the CRT electron beams that illuminate the red, blue, and green phosphors. RGB color space, now, uses for color scanner as well.

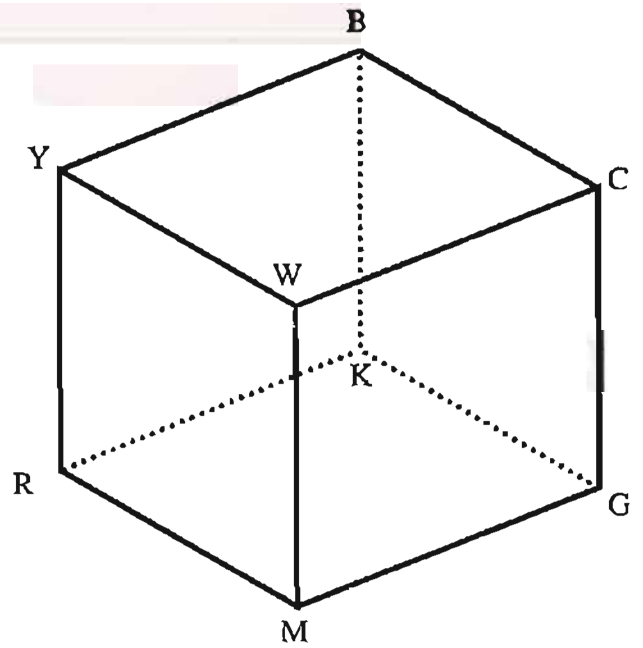


Figure 2-5 Computer Color space consists of RGB and CMY coordinate

The resultant RGB color space is a cube with the maximal intensity primaries (red, green, and blue) and their full intensity binary combinations (cyan, yellow, and magenta) forming the corners. White (mixture of all primaries) and black (no primaries) are located at opposite ends of the central diagonal of the cube.

2.1.3.5 CIE Color space

CIE color space is a physical description of light. It also incorporates data from color vision experiments. However, as with all studies, the design of questions influences their answers. The original CIE color vision data were collected under very specific viewing conditions which imposed certain constraints in generalizing the system to typical viewing conditions of display and hard copy colors.

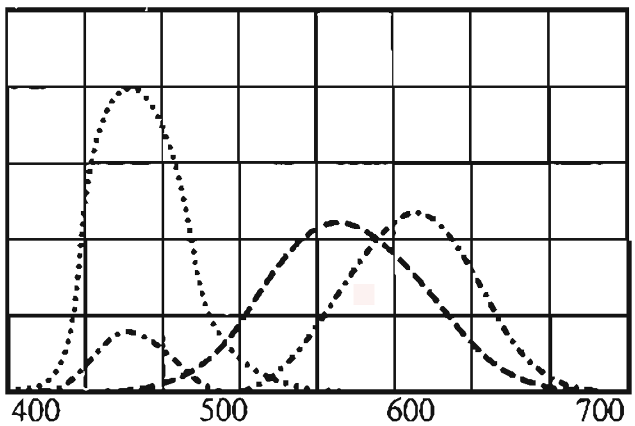


Figure 2.6 Responses of the average human eye as establish by the CIE in 1931

(a) CIE XYZ

Tristimulus values are the amount of X, Y and Z that contained in the mixture that expresses the absolute amount of a primary necessary for a color match. Two colors match when their tristimulus values are equal. Many different light distributions can produce the same set of tristimulus values.

The CIE tristimulus values can be expressed by

$$X = \int E_\lambda \bar{x} \Delta\lambda$$
$$Y = \int E_\lambda \bar{y} \Delta\lambda \quad (2.1)$$
$$Z = \int E_\lambda \bar{z} \Delta\lambda$$

-Chromaticity Coordinates: Color Plots in 2D Space

Three-dimensional spaces are complex to use. For easier interpretation, CIE space can be converted into two dimensions because each of its functions (x, y, z) is a proportion of the total amount of energy or

$$x = X/(X+Y+Z)$$
$$y = Y/(X+Y+Z) \quad (2.2)$$
$$z = 1-x-y$$

XYZ space is unique as compared to other three-primary color systems because it is based on real color matching data. When these functions are located on the chromaticity diagram, they form a shape that bounds all the colors we can see.

Advantages of CIE XYZ Space

There are many advantages of the CIE color system.

1. The CIE diagram is an international standard tool for comparing different color devices.

The chromaticity coordinates (x and y) and the measured luminance (Y) of a light provides a complete psychophysical description of a color. The diagram specifies colors for displays, printers, plotter, and film color.

2. For additive devices (like emissive displays, scanners and digital cameras), the diagram predicts color mixing results. Any mixture of two colors exists on a line connecting the two chromaticity points.

3. Color complements are easy to find in the diagram.

The spectral complement of a color can be located by connecting a line from a reference color through a reference white point in the CIE diagram.

4. The hue and saturation of a color can be derived from the diagram because dominant wavelength and excitation purity are graphically obvious and wavelength directly relates to hue and excitation purity to saturation.

5. The color capability of different hardware devices can be compared.

The CIE tristimulus values provide a 3D coordinate system which encompasses an entire color solid. The CIE system is thus useful as a quality metric for comparing the range of colors of different hardware devices: the greater the percentage of the entire color solid encompassed by the colors produced by the device, the greater its color capability.

Conventionally, a two-dimensional chromaticity diagram represents the color range of a computer output device. The triangle that formed by the x, y values of the device primaries is its color gamut. Commercially available color producing devices (like displays or printers) are not able to produce all perceptible colors (such as emerald green or deep purple).

6. The CIE 1964 color space describes the properties of color areas larger than two degrees and is thus more appropriate for evaluating the color of area-fill images in computer displays.

The 1964 Large Field CIE space is based on color mixing data obtained with ten degree fields. It is very similar to the standard two-degree diagram except in the blue region.

Limitations of CIE XYZ Space

In spite of its usefulness, the XYZ space has some disadvantages:

1. The CIE system usually requires the use of expensive equipment to make color measurements unless color matching data are provided (such as phosphor or ink chromaticity coordinates).

2. The CIE XYZ system does not predict color appearance.

Color judgments occur for large images and in complex scenes. A CIE specification of color does not indicate its appearance or differences in appearance between colors. For example, the chromaticity coordinates for a chocolate bar are nearly the same as for red lipstick. This similarity in appearance occurs because the CIE chromaticity coordinates are relative values which indicate information about the hue and saturation of a color, but not its brightness. In fact, red lipstick and chocolate bars would appear quite similar if the eye did not process luminance information. Thus, the inadequacy of the chromaticity diagram as a tool to determine color appearance is due to the exclusion of luminance in the CIE calculations. (However, the CIE tristimulus values for red lipstick and a chocolate bar are different.)

Uniform Color Spaces

Other color spaces have been developed to address the limitations of the CIE XYZ space. These spaces are generally known as uniform color spaces because they are more perceptually uniform. A uniform color space should allow:

· Prediction of similarities of two chromaticities

· Prediction of the amount of chromaticity change needed to create equal sized difference appearances (steps) in colors (for example, a graded scale of saturation for a given hue)

· Provision for choice of the number (N) of equally spaced colors for any N events or states

(b) CIELAB

CIELAB is the uniform color space metric recommended by the CIE. This space is often used to capture the color appearance of subtractive color mixtures. It is the standard color descriptor tool of the paint and dye industries.

CIELAB maps equally distinct color differences into equal Euclidean distances in the space. So equal distances in CIELAB space are useful for equally perceptible color differences on color plotters and printers or any subtractive color device. CIELAB retains many of the graphic advantages of the original CIE system.

LAB refers to the coefficients or coordinates of this space, L*, a*, and b*. While Lightness (L*) is the lightness, a* and b* are not linear transformations of the CIE. This is obvious in the following transformations of CIE XYZ space[9]:

$$L^* = 116(Y/Y_n)^{1/3} - 16$$
$$a^* = 500[(X/X_n)-(Y/Y_n)] \qquad (2.3)$$
$$b^* = 200[(Y/Y_n)^{1/3} - (Z/Z_n)^{1/3}]$$

where X/X_n, Y/Y_n, and $Z/Z_n > 0.01$

To evaluate the color we use color difference which the formula is;

$$\Delta E^*_{ab} = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2} \qquad (2.4)$$

The CIE system is used as a quality metric to compare the range of colors of different physical devices (such as color CRTs, printers, plotters, and film recorders). The 1964 Large Field CIE space is used to specify the color of colored images larger than two degrees. Its main contribution is to provide color difference equations which approximate the output of the black-white, red-green, and yellow-blue opponent mechanisms. CIELAB is used for hard copy color evaluation.

2.1.4 How Do Colors Mix?

There are two ways to create the colors we want. One is based on light whice the other is based on inks. The first is known as additive color mixing. The second is as subtractive color mixing. Additive color mixing is the way video monitors create colors. By emitting red, green and blue light in varying proportions and intensities, monitors call achieve all other colors. When pure red, green and blue lights are emitted at the same time with equal intensity, the visible result is white light[10].

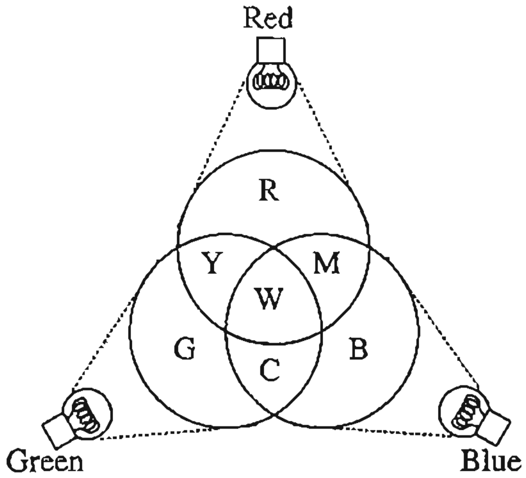


Figure 2.7 Additive Color mixing

When it comes to printing, we turn to subtractive color mixing. On a white surface, such as paper, we use inks or color film to subtract the colors we do not want. In printing, the three primary colors are cyan, magenta and yellow. Each color of ink absorbs or subtracts light of all colors except it's own color. Cyan ink, for instance, absorbs light of all colors but cyan. If all the primary colors are placed on a white page, then all light is absorbed, and the page appears black.

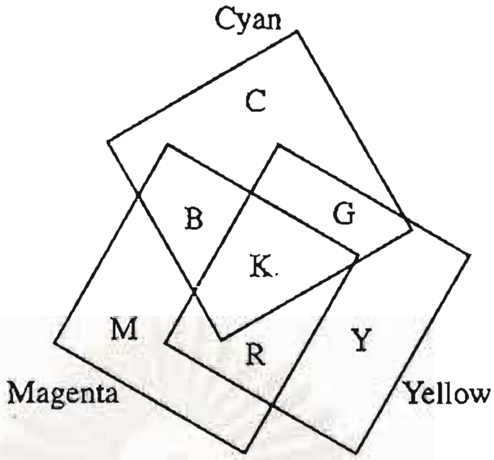


Figure 2.8 Subtractive Color mixing

2.1.5 *Black replacement*

In printing, although inks of the three primary colors call theoretically are used to print all other colors, black ink is also used as a fourth printing color (or "channel"). The black printer has two roles in the reproduction[11]. It extends the gamut of colors achievable in the darkest regions of the image. In addition, it can be used to replace appropriate amounts of the three-colored inks to ease control of color variation on the press. When the latter is constrained to near neutral areas it is called UCR, When it is applied to all colors it is called GCR[12, 13]. There are several reasons for this. One is economy. Black ink is less expensive than colored inks. Black call thus be achieved by using a single cheaper ink, instead of three colored inks. Other reasons include ensuring a truer black (less muddy than a black created with three colors) and faster drying time.

Theoretically, any color can be achieved using the three primary colors, cyan, magenta and yellow. Even that, it is possible to print grays and black using cyan, magenta and yellow. Unfortunately, doing so means using all three inks at the same time, on the same part of the image which is expensive. Therefore to reduce ink cost, a fourth black channel or a "K" has been introduced. Black created with a combination of other colors, a 3-color black, appears "muddy." The phenomenon linked to the impurity of inks- and printing 3-color blacks can result in a buildup of ink that impairs drying. Using black ink ensures sharper black in your output. (For the curious, the "K" used to designate black comes from the photographic world's use of "key" to enhance shadows)

Two techniques are used in color replacement:

1) Undercolor removal (UCR) uses black ink to replace the other process colors in the shadow areas of an image and in neutral shades.

2) Gray component replacement (GCR) involves a more general replacement with black being substituted over a greater color range (for neutral tones and for gray components of desaturated colors).

The printing with these process colors, CMY and K, is called Four-color printing. Unfortunately, there are others printing system that contributes modelizes the extension of the CMYK process to 5-color, 7-color and 9-color printing system[12].

2.1.6 *Color Transformation*

Digital imaging systems, whether for graphic arts, business, or scientific applications, usually require some form of panted output either as a final product or as a proof for evaluation. This output optimally preserves the full detail and color content of any digitized raster image. Many inexpensive digital electronic marking engines are available today which provide the necessary image detail and color gamut potential necessary for realizing these goals. A great deal of processing, however, is required to transform digitized color images to an appropriately matched printed image.

There are different available techniques for color transformations, namely.

2.1.6.1. Theoretical definition

This is the most simple and straightforward RGB-to-CMY color transformation by using the theoretical definition of subtractive colors. If the color is defined with 256 distinct level (in 8 bits), for example, for the 'basic' color (red, for example), the correspondent subtractive color, cyan, will be simply defined as:

$$\text{CYAN- value} = 255 - \text{RED value} \tag{2.5}$$

and the other two subtractive colors will be thus calculated

$$\text{MAGENTA value} = 255 - \text{GREEN value} \tag{2.6}$$

$$\text{YELLOW value} = 255 - \text{BLUE value} \tag{2.7}$$

Assuming that the additive and subtractive colors are fully complementary within the Visible Spectrum. However this is not true in practice, where the cyan, magenta and yellow inks are contaminated by impurities. Used in the earlier versions of the desktop publishing and/or reproduction software packages, this transformation is almost abandoned because there is NO COLOUR correction nor TONE Correction.

2.1.6.2. One-dimensional non-linear functions

The above mentioned method, after being somehow elaborated yields more effective color transformations. In this case we make usage of 'gradation' when transforming RGB values to CMY values (applying empirical methods in the majority of the cases and non-linear analytical expressions sometimes). In other words, we have one - dimensional correction curves which can be defined as:

$$\text{CYAN values} = \text{non-linearfunction of RED values} \tag{2.8}$$

MAGENTA values = non-linearfunction of GREEN values (2.9)

YELLOW values = non-linearfunction of BLUE values (2.10)

Such corrections, known as gradation corrections, are obtained very often by empirical means. Since this trial and error method do not and can not be defined with a mathematical and/or analytical expression to define this nonlinear transformation, we use look-up-tables (LUTs). In practice, a look-up-table consists of a table having a given number of entries (256 in our example), called addresses. They point into a specific location (256 locations in total according to our example) containing a given value predetermined empirically. With hardware, we perform such a 256 value to 256-value transformation by using a memory chip with 256 entries (8 address lines) mid thus with 256 addressable locations.

In practice, these 256 contents can not be determined individually. Therefore one uses a lower number of steps. For example, every 16 step (which corresponds to a step of 6.25%, in dot percentage) to determine empirically the content of these equally spaced 16 locations. In this case, to order to determine every intermediary value that was not experimentally defined we perform in interpolation. In our example, these 240 values are calculated off-line and then entered (prior to the transformation) into the table or the memory chip, as if they were 'really' determined.

It is obvious that this kind of color transformations is one-dimensional. In other words, the output cyan values depend only on the input red values disregarding the input green and blue values. The same applies for magenta and yellow values that depend respectively on input green and blue values.

2.1.6.3. Linear or matrix transformation or Regression

As opposed to the above mentioned one-dimensional color transformation, to compute the output cyan values (for example), we have 'some' interaction between the directly involved input color (red for cyan) and the other two non-involved input color values (green and blue for cyan). We apply a similar technique to compute magenta and yellow output values.

$$\text{CYAN} = (a_1 \times \text{RED}) + (a_2 \times \text{GREEN}) + (a_3 \times \text{BLUE}) \quad (2.11)$$

$$\text{MAGENTA} = (a_4 \times \text{RED}) + (a_5 \times \text{GREEN}) + (a_6 \times \text{BLUE}) \quad (2.12)$$

$$\text{YELLOW} = (a_7 \times \text{RED}) + (a_8 \times \text{GREEN}) + (a_9 \times \text{BLUE}) \quad (2.13)$$

This method utilizes a linear color transformation expressed with a 3 X 3 matrix. The different nine coefficients can be easily determined in function of the impurities of printing inks. This is a relatively simple method which can be implemented in software. This method which considers not only the directly involved input color values (red in the case of cyan) but also the other two input color values (green and blue for cyan), provide quite satisfactory results for applications involving desktop publishing and/or reproduction.

The polynomial regression is based on the assumption that the correlation between color spaces can be approximated by a set of simultaneous equations.

The schematic diagram of the regression method is depicted in Figure 2.9. Sample points in the source color space are selected and their color specifications in the destination space are measured. An equation is chosen for linking the source and destination color specifications.

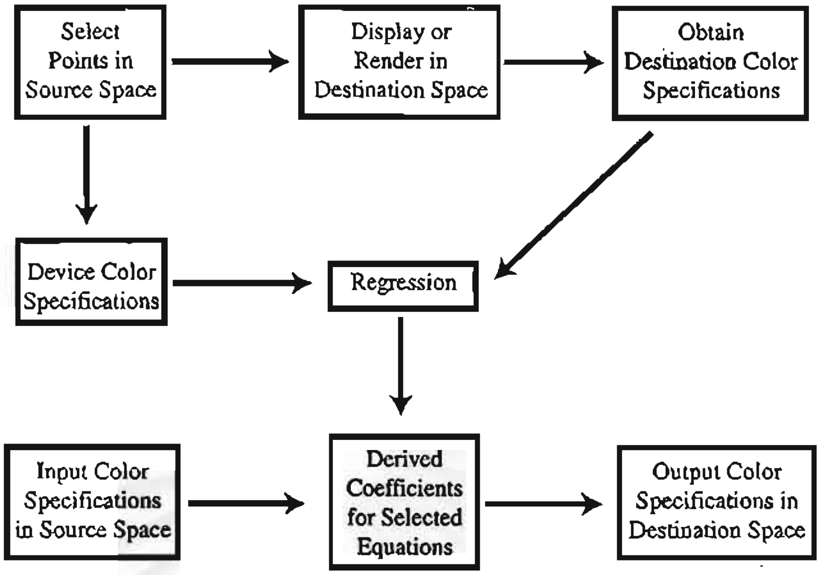


Figure 2-9 Schematic diagram of the regression method.

A regression is performed to select points with known color specifications in both source and destination spaces for deriving the coefficients of the polynomial. The only requirement is that the number of points should be higher than the number of polynomial terms; otherwise, there will be no unique solutions to the simultaneous equations because there are more unknown variables than equations. Using derived coefficients, one can plug the source specifications into the simultaneous equations to compute the destination specifications

Table 2.1 Some Samples of the Polynomials for Color Space Conversion are given;

1. $P(x,y,z) = a_1x+a_2y+a_3z$
2. $P(x,y,z) = a_0+a_1x+a_2y+a_3z$
3. $P(x,y,z) = a_1x+a_2y+a_3z+a_4xy+a_5yz+a_6zx$
4. $P(x,y,z) = a_0+a_1x+a_2y+a_3z+a_4xy+a_5yz+a_6zx+a_7xyz$
5. $P(x,y,z) = a_1x+a_2y+a_3z+a_4xy+a_5yz+a_6zx+a_7x^2+a_8y^2+a_9z^2$

6. $P(x,y,z) = a_0+a_1x+a_2y+a_3z+a_4xy+a_5yz+a_6zx+a_7x^2+a_8y^2+a_9z^2+a_{10}xyz$

7. $P(x,y,z) = a_0+a_1x+a_2y+a_3z+a_4xy+a_5yz+a_6zx+a_7x^2+a_8y^2+a_9z^2+a_{10}xyz+a_{11}x^3+a_{12}y^3$
$+a_{13}z^3$

8. $P(x,y,z) = a_0+a_1x+a_2y+a_3z+a_4xy+a_5yz+a_6zx+a_7x^2+a_8y^2+a_9z^2+a_{10}xyz+a_{11}x^3+a_{12}y^3$
$+a_{13}z^3+a_{14}xy^2+a_{15}x^2y+a_{16}yz^2+a_{17}y^2z+a_{18}z^2x+a_{19}zx^2$

The polynomial regression is an application of the multiple linear regression of m variables, where m is a number greater than the number of independent variables. The general approach of the linear regression with m variables is given as follows:

$$p_i = a_1v_{11} + a_2v_{12} + \text{- - - - - - - - - - -} + a_mv_{im} \qquad (2.14)$$

For the application to the polynomial regression with three independent variables x, y, and z: $v_1 = x$, $v_2 = y$, and $v_3 = z$

we then set

$v_4 = xy$, $v_5 = yz$, $v_6 = zx$, $v_7= x^2$, $v_8 =y^2$, $v_9 = z^2$, etc.

The coefficients are obtained by

$$a = (V\ V')^{-1}\ (VP) \qquad (2.15)$$

With n sets of inputs, V is a matrix of size m x n, where m is the number of terms in the polynomial. V' is the transpose of V that is obtained by interchanging the rows and columns of the matrix V, therefore, a matrix of size n x m. The product of VV' is an m x m symmetric matrix.

The sample how to find the coefficient of the six-term equation with eight data sets is used to illustrate in the APPENDIX B. Unfortunately, there are many application softwares which can be helped for finding them such as Mathametica, Mathlab, SPSS, etc. I choose SPSS for this procedure since it can share the data in the Excel table and easy to be used. For Mathametica, there is an addition module, MathLink, that can be used for linking to Excel.

Color transformation by using this method is a relatively simple method compare to many methods such as 3-D Look-Up Table. The sample points need not be uniformly spaced. This method provides quite satisfactory results. The conversion can be done by both directions, forward and reverse. All that require is to exchange the position of the input and output data for the regression program. Points outside the consideration data are able to be extrapolated. Because the polynomial coefficients are obtained by a global least square error minimization, the polynomial may not map the sample points to their original values. Several recent publications use this technique for color scanner and printer characterizations and calibrations. The adequacy of the method depends on the relationship between the source and destination spaces, the number and location of the points chosen for the regression, the number of terms in the polynomial, and the measurement errors. For nonlinear color space conversion, this regression method does not guarantee uniform accuracy across the entire color gamut; some regions, dark colors, for example, have higher errors than other areas. In general, the accuracy improves as the number of terms in the equation increases. The tradeoff is the higher computation cost and lower processing speed.

2.1.6.4 Linear Interpolation

The two-dimensional (bilinear) and three-dimensional (trilinear) linear interpolation is depicted in Figure 2.10 and Figure 2.11. A point p on the curve between the lattice points p_0 and p_1 is to be interpolated. The interpolated value $p_c(x)$ is linearly proportional to the ratio of $(x-x_0)/(x_1-x_0)$, where (x_1-x_0) is the projected length of the line segment connecting

p_0 and p_1, and $(x-x_0)$ is the projected distance of the point p to p_0.

$$p_c(x) = p(x_0) + [(x-x_0) / (x_1-x_0)] [p(x_1)-p(x_0)] \qquad (2.16)$$

The interpolation error is

$$e = p(x) - p_c(x) \qquad (2.17)$$

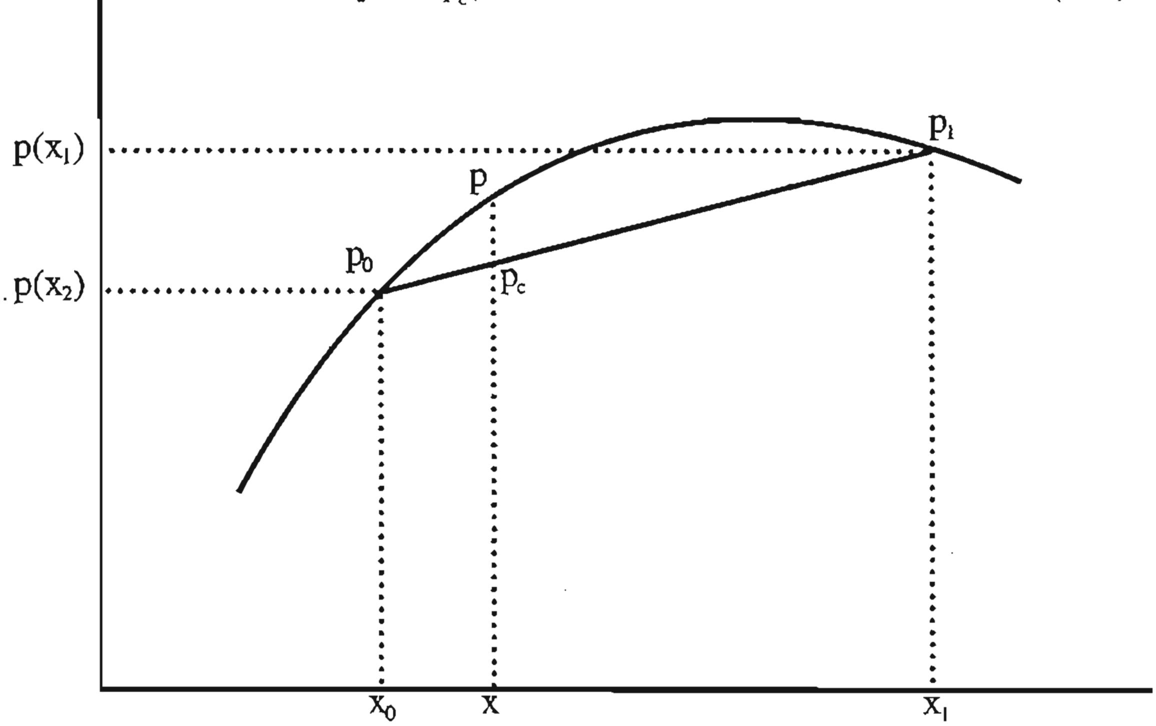


Figure 2-10 Linear interpolation

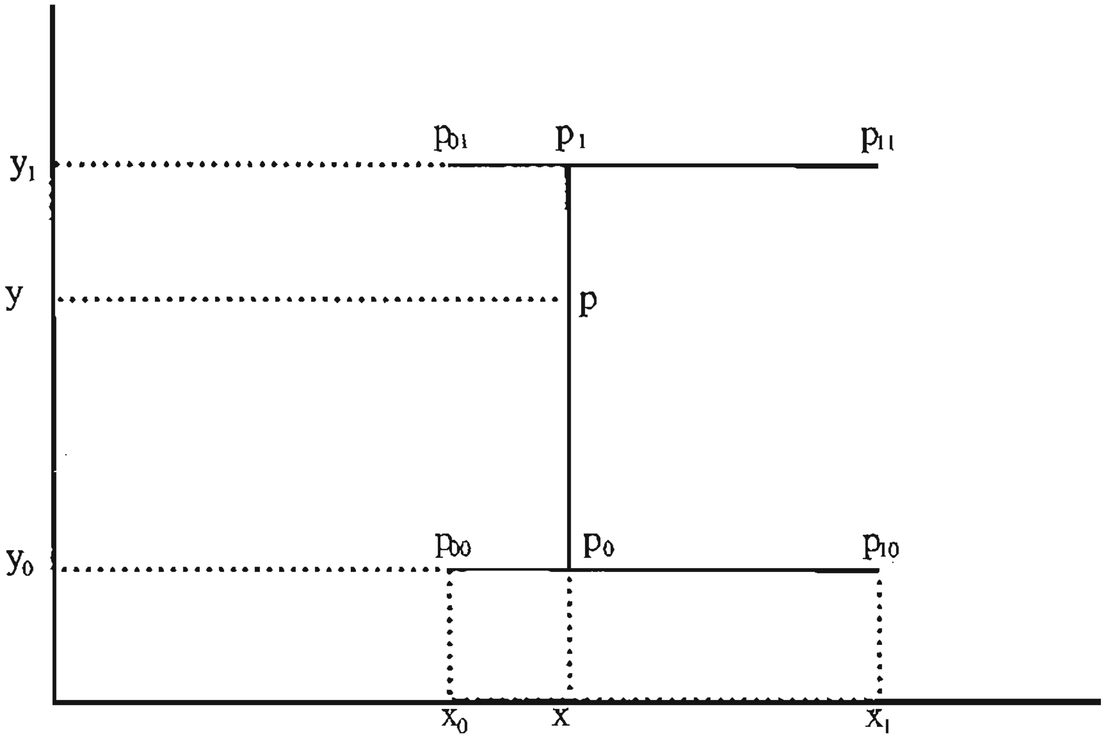


Figure 2-11 Bilinear interpolation

In two dimensions, (see Figure 2.11) one has a function of two variables p(x, y) and four lattice points $p_{00}(x_0, y_0)$, $p_{01}(x_0, y_1)$, $p_{10}(x_1, y_0)$, and $p_{11}(x_1, y_1)$. To obtain the value for point p, we first hold y_0 constant and apply the linear interpolation on lattice points p_{00} and p_{10} to obtain p_0:

$$p_0 = p_{00} + [(x-x_0) / (x_1-x_0)] (p_{10} - p_{00}) \quad (2.18)$$

Similarly, we calculate p_1 by keeping y_1 constant:

$$p_1 = p_{01} + [(x-x_0) / (x_1-x_0)] (p_{11} - p_{01}) \quad (2.19)$$

After obtaining p_0 and p_1, we again apply the linear interpolation to them by keeping x constants:

$$p(x,y) = p_0 + [(y-y_0)/(y_1-y_0)]\,(p_1 - p_0) \qquad (2.20)$$

Substituting Eqs. (4.18) and (4.19) into Eq. (4.20), we obtain

$$\begin{aligned} p(x,y) = \; & p_{00} + [(x-x_0)/(x_1-x_0)](p_{10}-p_{00}) \\ & + [(y-y_0)/(y_1-y_0)](p_{01}-p_{00}) \\ & + [(x-x_0)/(x_1-x_0)][(y-y_0)/(y_1-y_0)](p_{11}-p_{01}-p_{10}+p_{00}) \end{aligned} \qquad (2.21)$$

The trilinear equation is derived by applying the linear interpolation seven times (see Figure 2-12), three times each, to determine the points p_t and P_b as illustrated in the two-dimensional bilinear interpolation, then one more time to compute the point p:

$$p(x,y) = c_0+c_1\Delta x+c_2\Delta y+c_3\Delta z+c_4\Delta x\Delta y+c_5\Delta x\Delta z+c_6\Delta y\Delta z+c_7\Delta x\Delta y\Delta z \qquad (2.22)$$

where

$$\Delta x = x-x_0$$
$$\Delta y = y-y_0$$
$$\Delta z = z-z_0$$

$$c_0 = p_{000}$$
$$c_1 = (p_{100}-p_{000})/(x_1-x_0)$$
$$c_2 = (p_{010}-p_{000})/(y_1-y_0)$$
$$c_3 = (p_{001}-p_{000})/(z_1-z_0)$$
$$c_4 = (p_{110}-p_{010}-p_{100}+p_{000})/[(x_1-x_0)(y_1-y_0)]$$
$$c_5 = (p_{101}-p_{001}-p_{100}+p_{000})/[(x_1-x_0)(z_1-z_0)]$$
$$c_6 = (p_{011}-p_{001}-p_{010}+p_{000})/[(y_1-y_0)(z_1-z_0)]$$
$$c_7 = (p_{111}-p_{011}-p_{101}-p_{110}+p_{100}+p_{001}+p_{010} - p_{000})/[(x_1-x_0)(y_1-y_0)(z_1-z_0)]$$

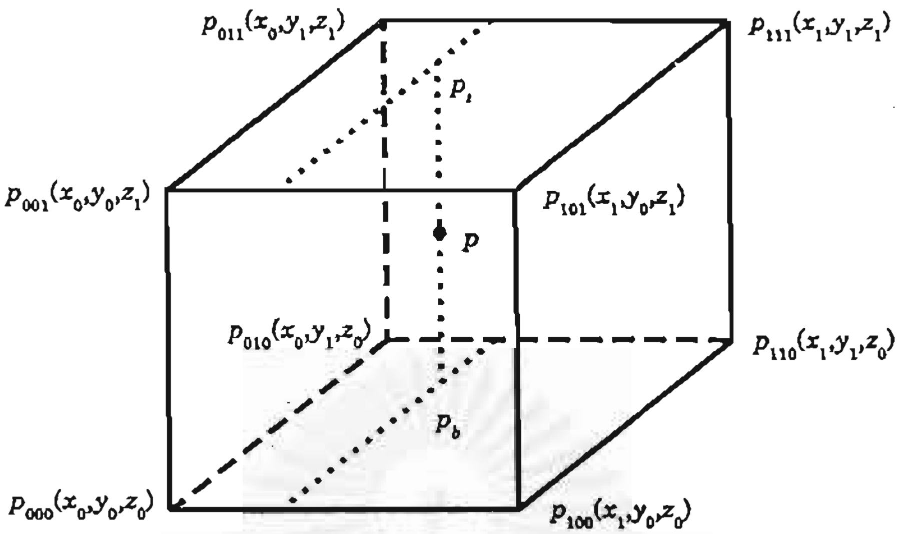


Figure 2-12 Trilinear interpolation

There is no need for a search mechanism to find the location of the point, because the cube is used as a whole. The computation cost, using all eight vertices and having eight terms in the equation, is higher than other 3D geometric interpolations.

Direct interpolation can be thought of as a piecewise linear model while multiple-linear regression represents a single linear or nonlinear model[15].

2.1.6.5 <u>3D Look Up Table with interpolation</u>

The use of three dimensional color look-up tables can provide an effective alternative to algorithm-based transforms. They are much faster and potentially much more accurate. The down side is they don't have "knobs" to quickly provide minor adjustments to the transform for changes in media or inks. Color look-up tables, in order to be practical, must be of a manageable size. A look-up table containing all possible printable colors would be far to massive to be of practical use. A smaller table combined with interpolation is required. Filling look-up tables requires a collection of print sample color measurements. Again, for practical reasons, minimizing the number of measurements is desired. Filling the look-up table for colors falling in between the sampled colors again requires the use of interpolation. A discussion of the interpolation requirements for color transformation follows.

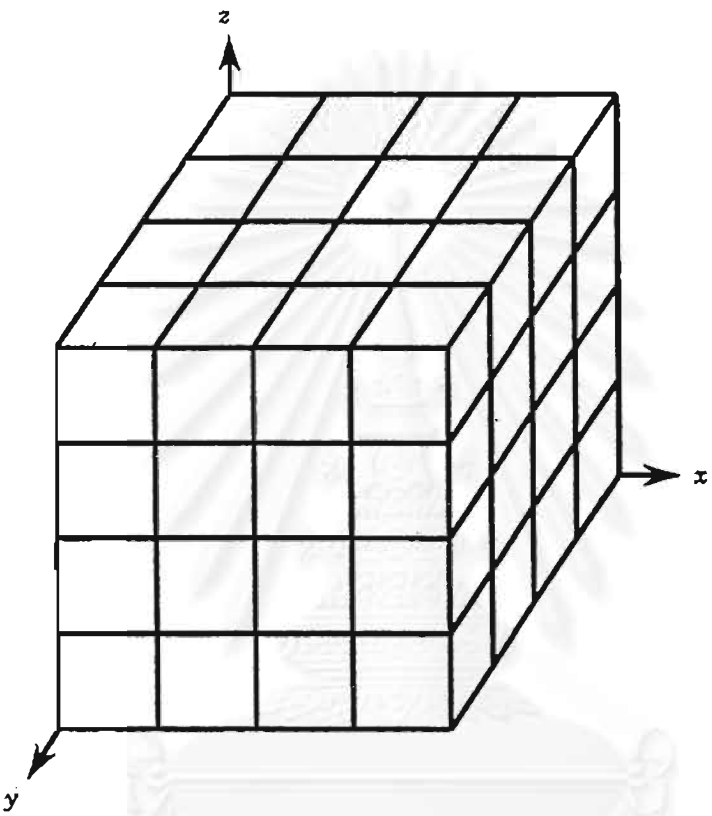


Figure 2-13 The five-level equal sampling of the input color space.

The three-dimensional (3D) lookup table consists of three parts

- packing (or partition) is a process that divides the domain of the source space and populates it with sample points to build the lookup table, normally is built by an equal step.

- extraction (or find) is the process to search for the cube that contains the point or color of interest.

- interpolation (or computation) is the process to calculate the destination result of the consider color in the cube. There are many geometrical interpolations which can employ to compute the color values of non-lattice points - prism, pyramid, tetrahedral-and many variations.

- Prism Interpolation

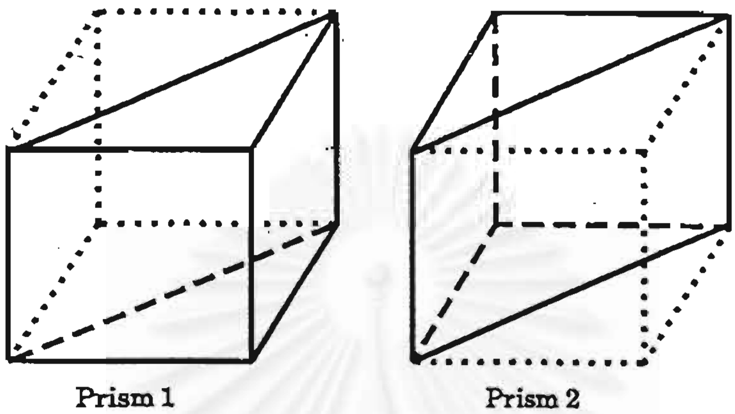


Figure 2-14 Prism interpolation.

If one cuts a cube diagonally into two halves as shown in Figure 2.14, one gets two prism shapes.

-Pyramid Interpolation

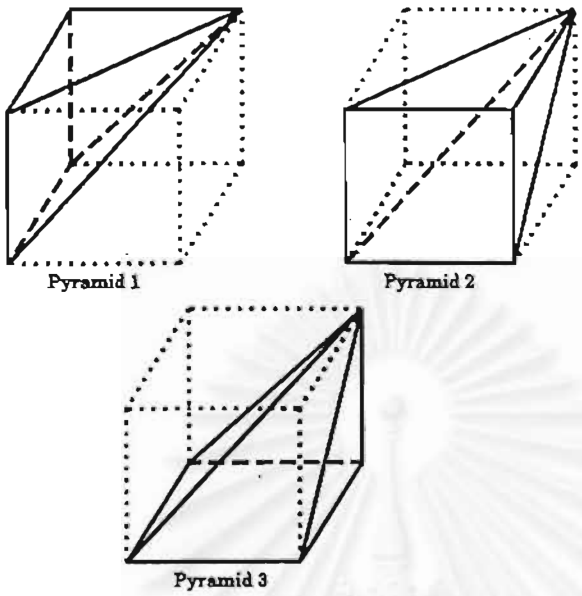


Figure 2-15 Pyramid interpolation.

For pyramid interpolation, the cube is sliced into three pieces. Each one takes a face as the pyramid base having its corners connected to a vertex in the opposite side as the apex (see Figure 2.15).

-Tetrahedral Interpolation

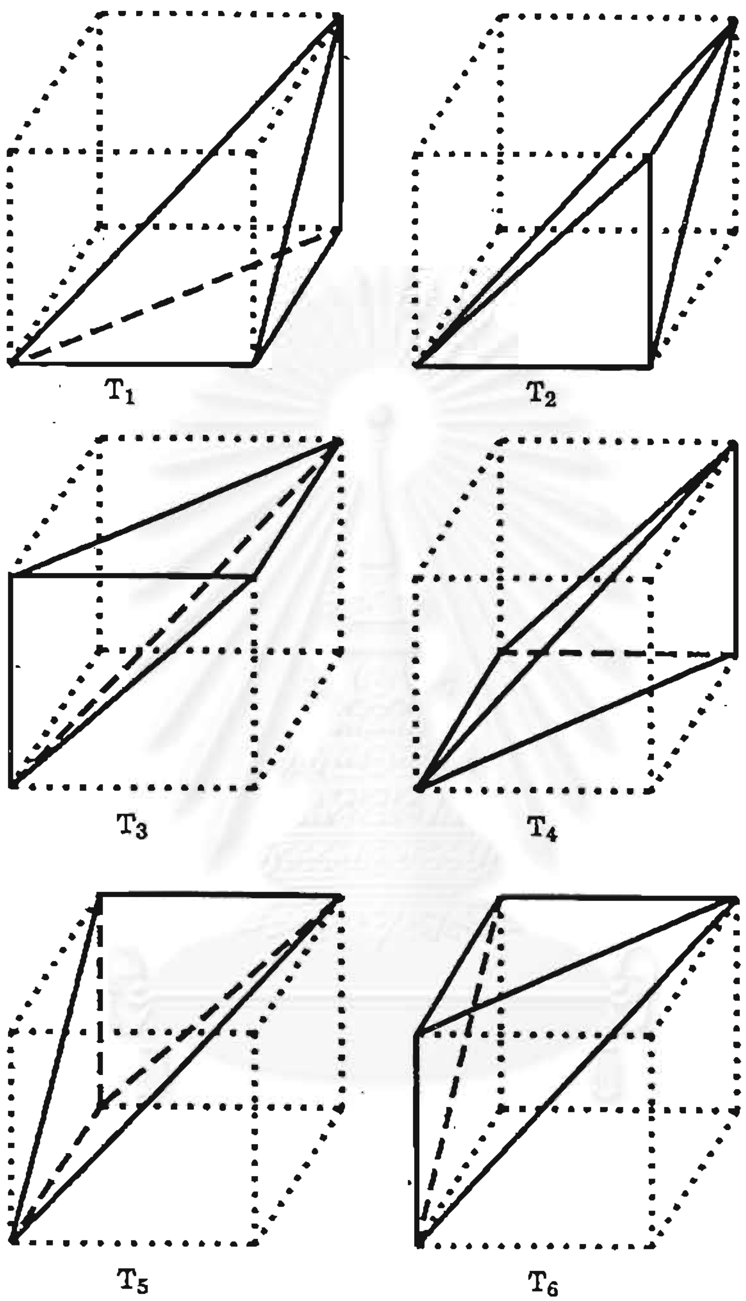


Figure 2-16 Tetrahedral interpolation.

The tetrahedral interpolation slices a cube into six tetrahedra; each has a triangle base, as shown in Figure 2-16

2.1.6.6 Non-Uniform Look Up Table

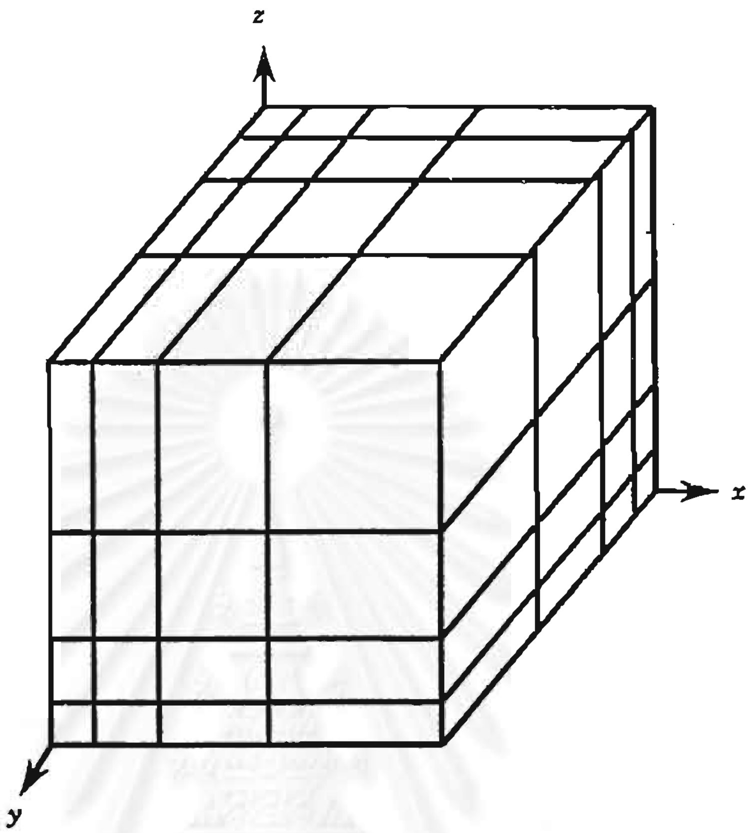


Figure 2-17 A five-level unequal sampling of the input color space.

3-D Look up table is not only a uniform cube shape but also a non-uniform. For non-uniform Look up table, with the packing each subcell is no longer a cube but a rectangular shape or even any geometric shapes.

The non-uniform LUT 's real benefit is the improvement in the interpolation accuracy and more uniform error distribution. It also reduces the implementation cost and simplifies the design without adding computation cost.

2.1.6.7 Special and combination techniques.

There are some benefits and disadvantage points on each technique. The combination technique can fill the gap and improve the process of transformation. Some techniques can be improved easily by additional special techniques.

Cellular Regression is a combination of 3D packing and polynomial regression. For instead of applying regression to the whole sampling data, we can group it into a small lattice cell and do regression to those groups of consider data. To cut the data into small cube, we will get only eight vertices of a cube that are used to derive the coefficients of a selected equation. That mean the maximum term in the equation cannot be more than the point. There are several special techniques to help, such as selections with respect to the polynomials, the regression points, and the cell sizes and shapes.

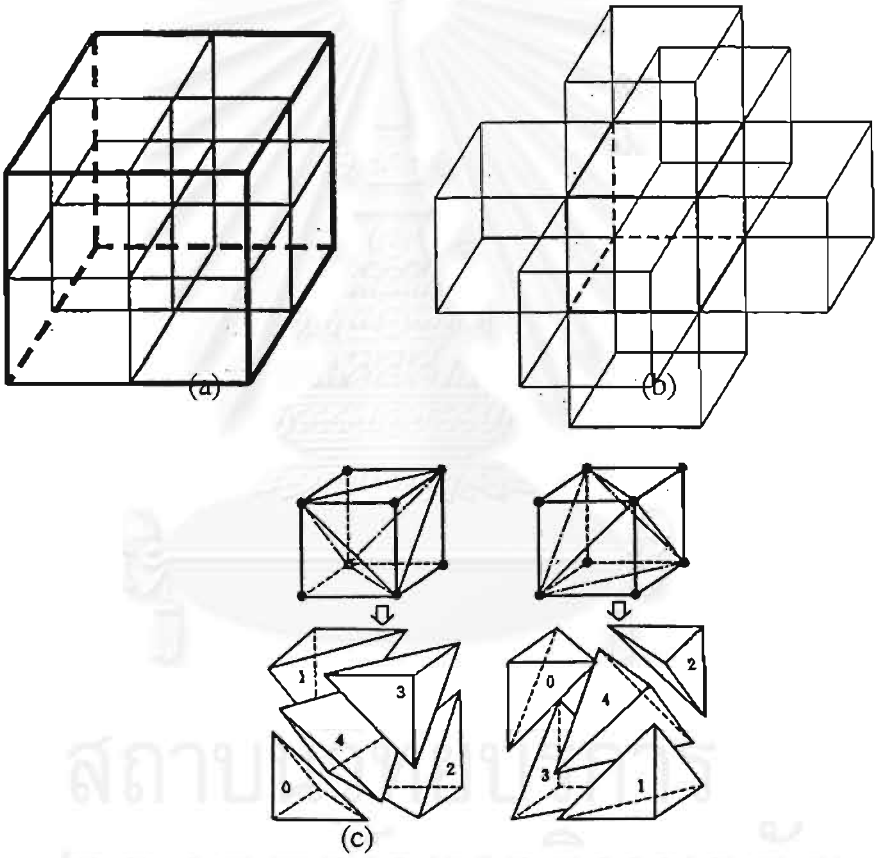


Figure 2-18 The special technique for approaching of the 3D lookup table with polynomial regression. (a) left is the double sampling rate, and (b) right is the inclusion of six neighboring cubes. (c) 4-Neighbors Interpolation[16]

The followings are the advantages comparable to the geometric interpolation;

1. There is no need to find the position of the interpolation point within the cube which is the same as trilinear interpolation.

2. It can accommodate any mathematical expression, such as square root, logarithm, and exponential terms.

3. There is no need of a uniform packing; it can apply to any 3D structure, such as distorted hexahedra.

4. It can have any number of terms in the equation as long as the number does not exceed the number of vertices in the cube.

3-D Barycentric interpolation[17] is another combination sample. It composes of the technique of 3D LUT and using special technique by weighting

. This is an improved method for transforming three dimensional image data from an RGB color space to a CMY or CMYK ink or dye color system.

Subdivided smaller color spaces masking [18],[19] is a kind of combination technique. It divided the whole color space into sub-divided smaller color spaces. Each sub-space was defined by non-linear fashion. After that, the linear regression employed to the sub-spaces individually.

2.2 Literature review.

2.2.1 Color space conversions

Alan Roberts and Adrian Ford complied the document of Color Space Conversions. They showed many equations for many color space conversions. They also gave the equation of the RGB to CMY color conversion by using color definition. The equations are as these;

$$\begin{aligned} \text{Cyan} &= 1 - \text{Red} \\ \text{Magenta} &= 1 - \text{Green} \\ \text{Yellow} &= 1 - \text{Blue} \end{aligned} \tag{2.23}$$

According to the equation 2.23, the normalization for the color values was necessary. For the space of Cyan, Magenta and Yellow, the color values are between 0 to 100. On the other hands, for the color space of Red, Green and Blue, the color values are between 0 to 255. To normalize the equation, this equation was replace.

$$\begin{aligned} \text{Cyan} / 100 &= 1 - \text{Red} / 255 \\ \text{Magenta} / 100 &= 1 - \text{Green} / 255 \\ \text{Yellow} / 100 &= 1 - \text{Blue} / 255 \end{aligned} \tag{2.24}$$

Or they can be reorganize in the form of ;

$$\begin{aligned} \text{Cyan} &= (255 - \text{Red}) / 2.55 \\ \text{Magenta} &= (255 - \text{Green}) / 2.55 \\ \text{Yellow} &= (255 - \text{Blue}) / 2.55 \end{aligned} \tag{2.25}$$

2.2.2 Gamma and linearity

In the same document, Alan Roberts and Adrian Ford said that the color space of RGB was the computer color space. Their values concern the voltage of the signal which sent to display on CRT or some RGB devices. In some cases, these voltages need to be modified by a power function. For a color computer system, the voltages can be replaced by the pixel values. The color relationships were;[20]

$$
\begin{aligned}
\text{Red} &= a * (\text{Red}' \wedge \text{gamma}) + b \\
\text{Green} &= a * (\text{Green}' \wedge \text{gamma}) + b \qquad (2.26) \\
\text{Blue} &= a * (\text{Blue}' \wedge \text{gamma}) + b
\end{aligned}
$$

2.2.3 *Color Scanner Calibration*

Henry R. Kang used the method of regression to do color transformation to apply for calibrating the color scanner. He did regression for transferring RGB of the values that obtain by the scanner to the XYZ data that measure from the test target. That means he transforms RGB to XYZ.[21]

2.2.4 *END (Equivalent Neutral Density)*

John Yule stated the END or Equivalent Neutral Density by printing the patch of CMY color and find out the point that CMY colors were printed together so that the mixtures were gray or black. The neutral density that measures from the mixed colors can be replaced by single color, black with the same density. The black density that can replace the CMY colors is called END.[22]

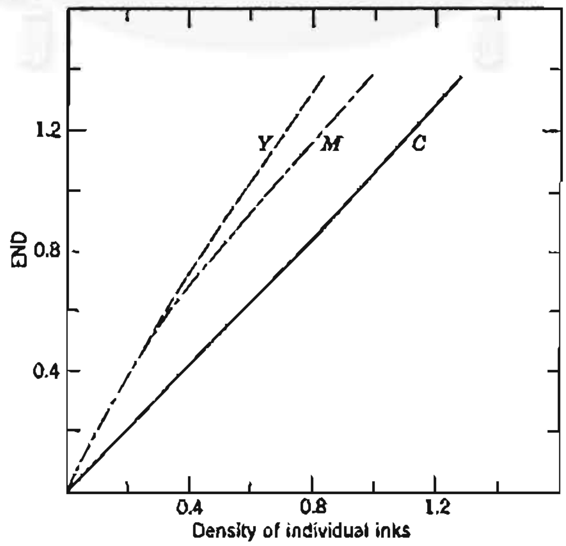


Figure 2-19 Relationship of equivalent neutral density to the individual ink

The Maximum black that can replace is equal to the smallest END of the mixed color. The color that contain the smallest END may not be the same color that have lowest density.

CHAPTER 3

EXPERIMENTAL

3.1 Materials

3.1.1 *Ink* : EPSON color ink cartridge S020110/PMICTC

EPSON black ink cartridge S020093/MJIC7

3.1.2 *Paper* : Kodak Inkjet Photographic Quality Paper, A4 210x297 mm 117 lbs.190g/ m^2

3.2 Apparatus

3.2.1 Inkjet Printer EPSON Photo 700

3.2.2 PC Pentium II 333 MHz., Ram 32 MB.

3.2.3 Agfa Color Test Chart IT8.7/2

3.2.4 Spectroscan GretagMacbeth

3.2.5 Software

3.2.5.1 Microsoft Excel 97

3.2.5.2 Adobe PhotoShop 4

3.2.5.3 SPSS 7.5

3.2.5.4 Logocolorlab 1

3.2.5.5 Microsoft Visual Basic

3.3 Procedure

A form of combination technique of the color transformation was used. There are three methods, definition, non-liner function and regression. They were used for transformation RGB to CMY color space. The technique of using black printer by END

(Equivalent Neutral Density) of John Yule was used. It was employed to create the 1D Look up table to transform CMY into CMYK Coordinate. The research can be separated the procedure into 4 steps, print characterization, RGB correction, regression and END LUT.

3.3.1 *Print Characterization*

The print characteristics are varied from printer to printer. The print characteristic is the way that how printer prints the color corresponding to the input data, CMYK or CMY. In order to know the print characteristic, the digital standard data of the test chart, IT8, was used. It is in the form of RGB data, denoted to $R_0G_0B_0$. The data was transferred to $C_0M_0Y_0$ data by the method of color definition. Microsoft Excel was chosen to convert the color as it is easy to use and follow through the progressive. The $C_0M_0Y_0$ data then was first saved in the text file. To convert the text file to $C_0M_0Y_0$ image TIFF file, the conversion was handled by the application software, named Logocolorlab. The TIFF file was sent to the printer by the print engine of the Adobe Photoshop version 4. It should be noted that this version of Photoshop is old version which CMS is not feasible whereby the print condition setting is easily controlled. The print out then was measured by the Spectroscan. The process is as follow;

3.3.1.1 The color definition method was used to transform the IT8.7 reference values of R_0,G_0,B_0 data (See also APPENDIX A) to $C_0M_0Y_0$. The following Equation was set;

$$C_0M_0Y_0 = \text{INT}((255\text{-}R_0G_0B_0)\text{*Maximumink}/2.55)/100 \qquad (3.1)$$

The Maximumink variable in the equation was contain to limit the maximum ink coverage of the print out. Not only the 100% ink was set, but the 80% maximum ink was test in the research also. The color values of them were plotted in the coordinate of a*b*.

3.3.1.2 The data of $C_0M_0Y_0$, first, was saved in the text file format. It was converted into the TIFF file format by running the LogocolorLab program.

The TIFF file then was opened by Photoshop to print out to Epson Photo 700 inkjet printer. The Color Setting in Photoshop program should be fixed as follow;

-Printing Ink Setup

Reset Dot Gain to "0"

-Separation Setup

Reset Black Generation to "None"

Reset Total Ink to "300"

The print out is the image of the color patch that composes of the combination set of Cyan, Magenta and Yellow ink. At this time, the black ink was not printed. These printout patches indicated the print characteristic by which the data that correspond to it was noted.

3.3.1.3 The print characteristic patch was measured by the Spectroscan to obtain the set of $X_pY_pZ_p$ data. With the $X_pY_pZ_p$ and $R_0G_0B_0$ data, the correlation graph was plotted to determine the linearization.

3.3.2 *RGB Correction*

Before the regression can be applied, it should be better to modify the $R_0G_0B_0$ data so that it would be more suitable to the $X_pY_pZ_p$. This process is called RGB Correction. To do RGB Correction, the power "p" was applied to the $R_0G_0B_0$ data; when p is odd number that makes the $(RGB)^p$ linear to XYZ. The modified value of $R_0G_0B_0$ was called $R_mG_mB_m$. The power "p" was varied from 1, 2 and 3 in the research. The graphs of each set of $R_mG_mB_m$ against $X_pY_pZ_p$ were plotted to determine if the linearity became. The best "p" was chosen and used for correcting RGB data.

3.3.3 *Regression*

The linear regression is based on the assumption that the correlation between color spaces can be approximated by a set of simultaneous equations. In this case, the correlation between RGB and XYZ were taken for doing regression. The $R_mG_mB_m$ data from the previous process and the $X_pY_pZ_p$ data that was obtained by measuring from the printer patches were investigated to find the coefficients of the equation. There are many equations that can be fitted for transferring. In the research the following equations were chosen from the table 2.1 to compare the result of transferring;

1. $P(x,y,z) = a_0+a_1x+a_2y+a_3z$ (3.2)

2. $P(x,y,z) = a_0+a_1x+a_2y+a_3z+a_4xy+a_5yz+a_6zx+a_7xyz$ (3.3)

3. $P(x,y,z) = a_0+a_1x+a_2y+a_3z+a_4xy+a_5yz+a_6zx+a_7x^2+a_8y^2+a_9z^2+a_{10}xyz$ (3.4)

4. $P(x,y,z) = a_0+a_1x+a_2y+a_3z+a_4xy+a_5yz+a_6zx+a_7x^2+a_8y^2+a_9z^2+a_{10}xyz$
$+a_{11}x^3+a_{12}y^3+a_{13}z^3+a_{14}xy^2+a_{15}x^2y+a_{16}yz^2+a_{17}y^2z+a_{18}z^2x+a_{19}zx^2$ (3.5)

To do the regression is meant to find out the coefficients of each equation. The SPSS program was used to help finding them. Four transfer equations was obtained. The $X_pY_pZ_p$ data were used to substitute into the equations for checking the error by plotting the RGB values that came out to the $R_mG_mB_m$. The variables in the transfer equations were replaced again by the $X_0Y_0Z_0$ that measure from the standard IT8.7 Test Chart (hard copy). Then, the RGB values that came out would be the modified RGB, denoted $R_{mc}G_{mc}B_{mc}$. The $R_{mc}G_{mc}B_{mc}$ should be the RGB that would produce the color patch that closed to those of IT8 standard test chart.

Since the $R_{mc}G_{mc}B_{mc}$ resulted from the equation that was done regression by the $R_mG_mB_m$, and the $R_mG_mB_m$ was the modified RGB in the process of RGB correction, it was necessary to do demodification before use. To do demodify $R_{mc}G_{mc}B_{mc}$, the invert power "1/p" was taken to power to the $R_{mc}G_{mc}B_{mc}$ to obtain the $R_cG_cB_c$ values.

The $R_cG_cB_c$ then were transformed to $C_cM_cY_c$ by the definition method again using the equation 3.1

The $C_cM_cY_c$ were converted to TIFF files by Logocolorlab, and printed by the same color condition in Photoshop to the printer. The prints out then were measured by the Spectroscan to obtain the sets of $X_cY_cZ_c$ and $L_ca_cb_c$ for evaluation to the original IT8 Test Chart.

The graph of $X_cY_cZ_c$ against $X_0Y_0Z_0$ were plotted and the colors were evaluated based on color difference that calculated by equation 2.4.

3.3.4 END LUT.

This process was modified from the idea of END of John Yule that stated in the literature review. In stead of using density of the black ink to be the equivalent density to the color mixture CMY, the CIE color value, Lab, was used. The color differences were used to judge the equivalence of the Black ink to CMY color mixture. The 1D END LUT then was created and listed in the function sub-routine of the Visual Basic program. The process to transform CMY to CMYK was operated through the cooperation of Excel data. The steps in doing transformation are as follow;

3.3.4.1 The color patch of the mixture of CMY colors values that close color to the K value were defined as follow;

C	M	Y	K
0	0	0	0
0	0	2	0
0	0	4	0
2	0	0	0
2	0	2	0
2	0	4	0

4	0	0	0
4	0	2	0
4	0	4	0
1	5	1	0
1	5	3	0
1	5	5	0
3	5	1	0
3	5	3	0
3	5	5	0
5	5	1	0
5	5	3	0
5	5	5	0
5	5	7	0
5	5	9	0
7	5	5	0
7	5	7	0
7	5	9	0
9	5	5	0
9	5	7	0
9	5	9	0
6	10	6	0
6	10	8	0
6	10	10	0
8	10	6	0
8	10	8	0
8	10	10	0
10	10	6	0
10	10	8	0
10	10	10	0
10	10	12	0
10	10	14	0
12	10	10	0
12	10	12	0
12	10	14	0
14	10	10	0
14	10	12	0
14	10	14	0
11	15	11	0
11	15	13	0
11	15	15	0
13	15	11	0
13	15	13	0
13	15	15	0
15	15	11	0
15	15	13	0
15	15	15	0
15	15	17	0
15	15	19	0
17	15	15	0
17	15	17	0
17	15	19	0
19	15	15	0
19	15	17	0
19	15	19	0

16	20	16	0
16	20	18	0
16	20	20	0
18	20	16	0
18	20	18	0
18	20	20	0
20	20	16	0
20	20	18	0
20	20	20	0
20	20	22	0
20	20	24	0
22	20	20	0
22	20	22	0
22	20	24	0
24	20	20	0
24	20	22	0
24	20	24	0
21	25	21	0
21	25	23	0
21	25	25	0
23	25	21	0
23	25	23	0
23	25	25	0
25	25	21	0
25	25	23	0
25	25	25	0
25	25	27	0
25	25	29	0
27	25	25	0
27	25	27	0
27	25	29	0
29	25	25	0
29	25	27	0
29	25	29	0
26	30	26	0
26	30	28	0
26	30	30	0
28	30	26	0
28	30	28	0
28	30	30	0
30	30	26	0
30	30	28	0
30	30	30	0
30	30	32	0
30	30	34	0
32	30	30	0
32	30	32	0
32	30	34	0
34	30	30	0
34	30	32	0
34	30	34	0
31	35	31	0
31	35	33	0
31	35	35	0

33	35	31	0	42	40	44	0
33	35	33	0	44	40	40	0
33	35	35	0	44	40	42	0
35	35	31	0	44	40	44	0
35	35	33	0	41	45	41	0
35	35	35	0	41	45	43	0
35	35	37	0	41	45	45	0
35	35	39	0	43	45	41	0
37	35	35	0	43	45	43	0
37	35	37	0	43	45	45	0
37	35	39	0	45	45	41	0
39	35	35	0	45	45	43	0
39	35	37	0	45	45	45	0
39	35	39	0	45	45	47	0
36	40	36	0	45	45	49	0
36	40	38	0	47	45	45	0
36	40	40	0	47	45	47	0
38	40	36	0	47	45	49	0
38	40	38	0	49	45	45	0
38	40	40	0	49	45	47	0
40	40	36	0	49	45	49	0
40	40	38	0	46	50	46	0
40	40	40	0	46	50	48	0
40	40	42	0	46	50	50	0
40	40	44	0	48	50	46	0
42	40	40	0	48	50	48	0
42	40	42	0	48	50	50	0

50	50	46	0
50	50	48	0
50	50	50	0
50	50	52	0
50	50	54	0
52	50	50	0
52	50	52	0
52	50	54	0
54	50	50	0
54	50	52	0
54	50	54	0
51	55	51	0
51	55	53	0
51	55	55	0
53	55	51	0
53	55	53	0
53	55	55	0
55	55	51	0
55	55	53	0
55	55	55	0
55	55	57	0
55	55	59	0
57	55	55	0
57	55	57	0
57	55	59	0
59	55	55	0
59	55	57	0

59	55	59	0
56	60	56	0
56	60	58	0
56	60	60	0
58	60	56	0
58	60	58	0
58	60	60	0
60	60	56	0
60	60	58	0
60	60	60	0
60	60	62	0
60	60	64	0
62	60	60	0
62	60	62	0
62	60	64	0
64	60	60	0
64	60	62	0
64	60	64	0
61	65	61	0
61	65	63	0
61	65	65	0
63	65	61	0
63	65	63	0
63	65	65	0
65	65	61	0
65	65	63	0
65	65	65	0

65	65	67	0
65	65	69	0
67	65	65	0
67	65	67	0
67	65	69	0
69	65	65	0
69	65	67	0
69	65	69	0
66	70	66	0
66	70	68	0
66	70	70	0
68	70	66	0
68	70	68	0
68	70	70	0
70	70	66	0
70	70	68	0
70	70	70	0
70	70	72	0
70	70	74	0
72	70	70	0
72	70	72	0
72	70	74	0
74	70	70	0
74	70	72	0
74	70	74	0
71	75	71	0
71	75	73	0
71	75	75	0
73	75	71	0
73	75	73	0
73	75	75	0
75	75	71	0
75	75	73	0
75	75	75	0
75	75	77	0
75	75	79	0
77	75	75	0
77	75	77	0
77	75	79	0
79	75	75	0
79	75	77	0
79	75	79	0
76	80	76	0
76	80	78	0
76	80	80	0
78	80	76	0
78	80	78	0
78	80	80	0
80	80	76	0
80	80	78	0
80	80	80	0
80	80	82	0
80	80	84	0
82	80	80	0

82	80	82	0
82	80	84	0
84	80	80	0
84	80	82	0
84	80	84	0
81	85	81	0
81	85	83	0
81	85	85	0
83	85	81	0
83	85	83	0
83	85	85	0
85	85	81	0
85	85	83	0
85	85	85	0
85	85	87	0
85	85	89	0
87	85	85	0
87	85	87	0
87	85	89	0
89	85	85	0
89	85	87	0
89	85	89	0
86	90	86	0
86	90	88	0
86	90	90	0
88	90	86	0
88	90	88	0
88	90	90	0
90	90	86	0
90	90	88	0
90	90	90	0
90	90	92	0
90	90	94	0
92	90	90	0
92	90	92	0
92	90	94	0
94	90	90	0
94	90	92	0
94	90	94	0
91	95	91	0
91	95	93	0
91	95	95	0
93	95	91	0
93	95	93	0
93	95	95	0
95	95	91	0
95	95	93	0
95	95	95	0
95	95	97	0
95	95	99	0
97	95	95	0
97	95	97	0
97	95	99	0
99	95	95	0

99	95	97	0
99	95	99	0
96	100	96	0
96	100	98	0
96	100	100	0
98	100	96	0
98	100	98	0
98	100	100	0
100	100	96	0
100	100	98	0
100	100	100	0
0	0	0	5
0	0	0	10
0	0	0	15
0	0	0	20
0	0	0	25
0	0	0	30
0	0	0	35
0	0	0	40
0	0	0	45
0	0	0	50
0	0	0	55
0	0	0	60
0	0	0	65
0	0	0	70
0	0	0	75
0	0	0	80
0	0	0	85
0	0	0	90
0	0	0	95
0	0	0	100

3.2.4.2 The C, M, Y and K values were used to generate a TIFF file by LogocolorLab; and then was sent to print through Photoshop program with controlled condition. The obtained color patches were measured by spectroscan to obtain the set of Lab values.

3.2.4.3 The set of Lab values were separated into 2 sets: Chromatic and Achromatic neutral color mixture.

3.2.4.4 Chromatic set was compared to the Achromatic set to find out the patches which gave closest color values, Lab. The color differences were used to evaluate the similarity.

3.2.4.5 The colors in the first set that consists of CMY could be replaced by the color in the second set that consists of only Black ink which had the same color value.

3.2.4.6 Each step of 21 color patch varied from 0 to 100% out interval of 5%. The average method, or bilinear interpolation was used to find the inter color between the steps.

3.2.4.7 To transform the CMY to CMYK by this LUT, the color values, $C_cM_cY_c$ from the regression process was passed to the following "LUT" sub-procedure of Excel;

```
Function LUT(Cin, Min, Yin, Color)
Dim C(21), M(21), Y(21), K(21), I
Dim Cup, Mup, Yup, Clow, Mlow, Ylow, Kup, Klow, IC, IM, IY
Dim CK, MK, YK, KK
Dim Cout, Mout, Yout, Kout
'
'LUT of END
'
C(0) = 0: M(0) = 0: Y(0) = 0: K(0) = 0
C(1) = 5: M(1) = 5: Y(1) = 5: K(1) = 5
C(2) = 10: M(2) = 10: Y(2) = 10: K(2) = 10
```

```
C(3) = 15: M(3) = 15: Y(3) = 17: K(3) = 15
C(4) = 20: M(4) = 20: Y(4) = 22: K(4) = 20
C(5) = 25: M(5) = 25: Y(5) = 27: K(5) = 25
C(6) = 30: M(6) = 30: Y(6) = 30: K(6) = 30
C(7) = 35: M(7) = 35: Y(7) = 35: K(7) = 35
C(8) = 40: M(8) = 40: Y(8) = 42: K(8) = 40
C(9) = 45: M(9) = 45: Y(9) = 45: K(9) = 45
C(10) = 50: M(10) = 50: Y(10) = 50: K(10) = 50
C(11) = 55: M(11) = 55: Y(11) = 55: K(11) = 55
C(12) = 60: M(12) = 60: Y(12) = 60: K(12) = 60
C(13) = 65: M(13) = 65: Y(13) = 65: K(13) = 65
C(14) = 68: M(14) = 70: Y(14) = 70: K(14) = 70
C(15) = 71: M(15) = 75: Y(15) = 73: K(15) = 75
C(16) = 78: M(16) = 80: Y(16) = 80: K(16) = 80
C(17) = 83: M(17) = 85: Y(17) = 85: K(17) = 85
C(18) = 88: M(18) = 90: Y(18) = 90: K(18) = 90
C(19) = 95: M(19) = 95: Y(19) = 95: K(19) = 95
C(20) = 98: M(20) = 100: Y(20) = 98: K(20) = 100
C(21) = 100: M(21) = 100: Y(21) = 100: K(21) = 100
'
'Find maximum of I
'
If Cin * Min * Yin = 0 Then
    KK = 0
    CK = 0
    MK = 0
    YK = 0
```

```
Else
    For I = 1 To 21
        If C(I - 1) < Cin And Cin <= C(I) Then IC = I
        If M(I - 1) < Min And Min <= M(I) Then IM = I
        If Y(I - 1) < Yin And Yin <= Y(I) Then IY = I
    Next
'
'If C is the minimum END
'
    If IC <= IM And IC <= IY Then
        IM = 99: IY = 99
        Cup = C(IC - 1): Mup = M(IC - 1): Yup = Y(IC - 1): Kup = K(IC - 1)
        Clow = C(IC): Mlow = M(IC): Ylow = Y(IC): Klow = K(IC)
        CK = Cin
        MK = Mlow + (Cin - Clow) * ((Mup - Mlow) / (Cup - Clow))
        YK = Ylow + (Cin - Clow) * ((Yup - Ylow) / (Cup - Clow))
        KK = Klow + (Cin - Clow) * ((Kup - Klow) / (Cup - Clow))
    End If
'
'If M is the minimum END
'
    If IM <= IC And IM <= IY Then
        IC = 99: IY = 99
        Cup = C(IM - 1): Mup = M(IM - 1): Yup = Y(IM - 1): Kup = K(IM -
1)
        Clow = C(IM): Mlow = M(IM): Ylow = Y(IM): Klow = K(IM)
        MK = Min
```

```
        CK = Clow + (Min - Mlow) * ((Cup - Clow) / (Mup - Mlow))
        YK = Ylow + (Min - Mlow) * ((Yup - Ylow) / (Mup - Mlow))
        KK = Klow + (Min - Mlow) * ((Kup - Klow) / (Mup - Mlow))
    End If
'
'If Y is the minimum END
'
    If IY <= IM And IY <= IC Then
        IC = 99: IM = 99
        Cup = C(IY - 1): Mup = M(IY - 1): Yup = Y(IY - 1): Kup = K(IY - 1)
        Clow = C(IY): Mlow = M(IY): Ylow = Y(IY): Klow = K(IY)
        YK = Yin
        MK = Mlow + (Yin - Ylow) * ((Mup - Mlow) / (Yup - Ylow))
        CK = Clow + (Yin - Ylow) * ((Cup - Clow) / (Yup - Ylow))
        KK = Klow + (Yin - Ylow) * ((Kup - Klow) / (Yup - Ylow))
    End If
'
'Find Exact Maximum CMYK
'
End If
Kout = KK
Cout = Cin - CK
Mout = Min - MK
Yout = Yin - YK
If Color = 1 Then LUT = Cout
If Color = 2 Then LUT = Mout
If Color = 3 Then LUT = Yout
```

If Color = 4 Then LUT = Kout

End Function

Note that this "LUT" is created by using the Microsoft Visual Basic. It firstly recognized the range of the given C, M, and Y values in the END table and secondly sorted for the lowest amount of CMY in the END table. The function, then, calculated the portion of C, M and Y that could be substituted by the appropriate portion of K. The new set of data which called NewC, NewM, NewY and NewK were generated by the function to adjust the amount of CMY mixture and replaced by the appropriated K values.

The NewC, NewM and NewY are the excessive value of C, M and Y that cannot be adjusted by NewK.

3.2.4.8 The $C_cM_cY_c$ color values were sent to the subroutine "LUT". The new transformed sets of NewC, NewM, NewY and NewK values then be converted to TIFF by LogocolorLab, opened by Photoshop and then were sent to print.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Print Characteristic

With the simplest color transformation technique, using color definition, the RGB color values were transformed by the equation 3.1. The maximum ink settings were applied, 100% and 80%. After conversion to TIFF files and print out to the inkjet printer, the color values were measured. Figure 4-1 shows the a*,b* coordinate of their colors. The color values, a*b*, of the IT8.7 test chart were also included in this graph. The graph shows that;

4.1.1 Epson Stylus Photo 700 printer has color gamut bigger than that in of the IT8.7 test target.

4.1.2 When the maximum ink was changed from 100% to 80%, the color gamut was reduced, consequently.

4.1.3 The color gamut of the maximum ink at 80% is smaller than the gamut of the IT8.7 test target. This imfers that the inkjet cannot be calibrated to match all the colors in the test target by this setting.

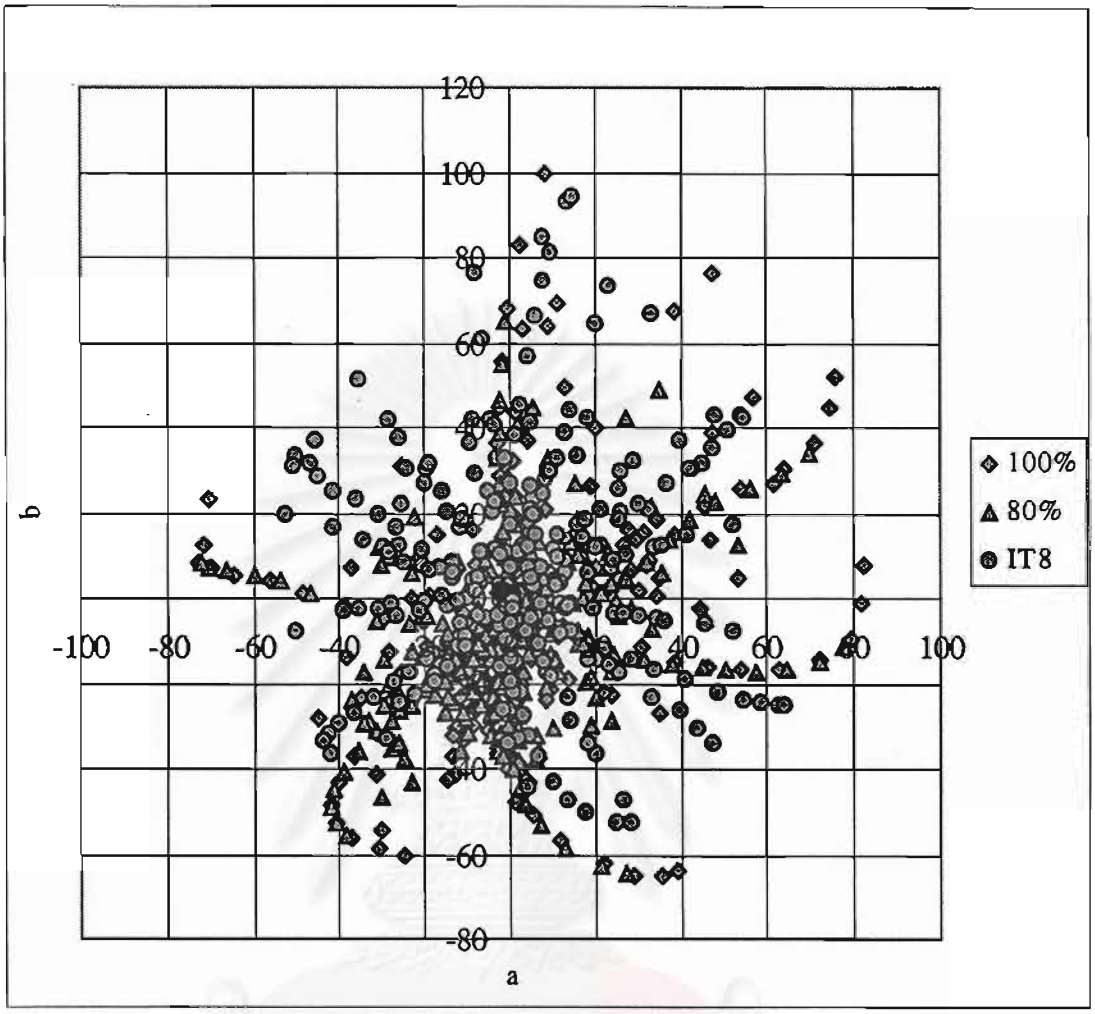


Figure 4-1 Maximum ink effect

4.2 RGB Correction.

The relationship of modified RGB or $R_mG_mB_m$ against the $X_pY_pZ_p$ of the printer by varying the power "p" are plotted and shown in the figure 4-2, 4-3, and 4-4. The best power value found in those graphs should be 2 as it showed linearized manner better than the others.

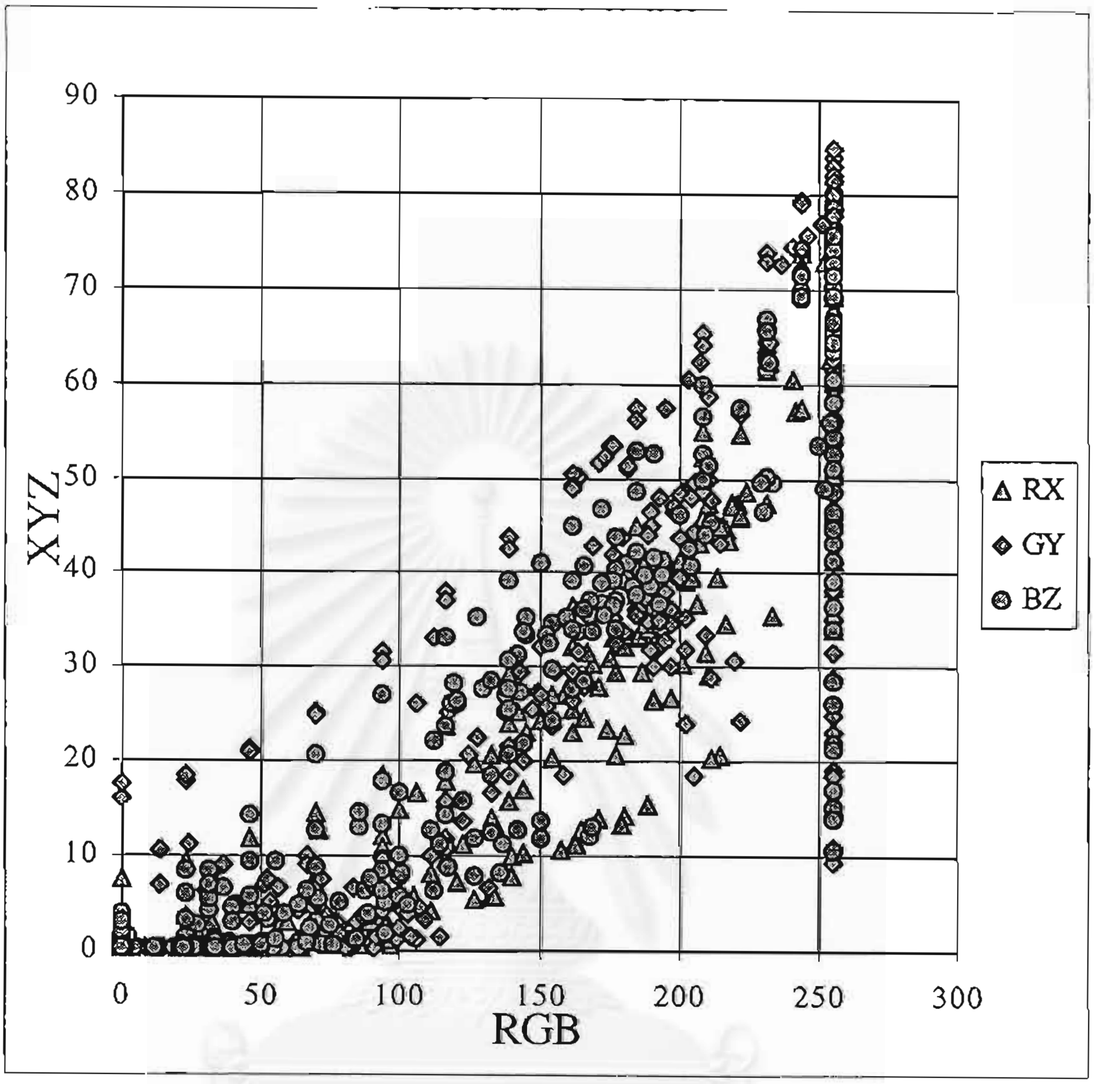


Figure 4-2 $R_mG_mB_m$ VS $X_pY_pZ_p$ with no modification

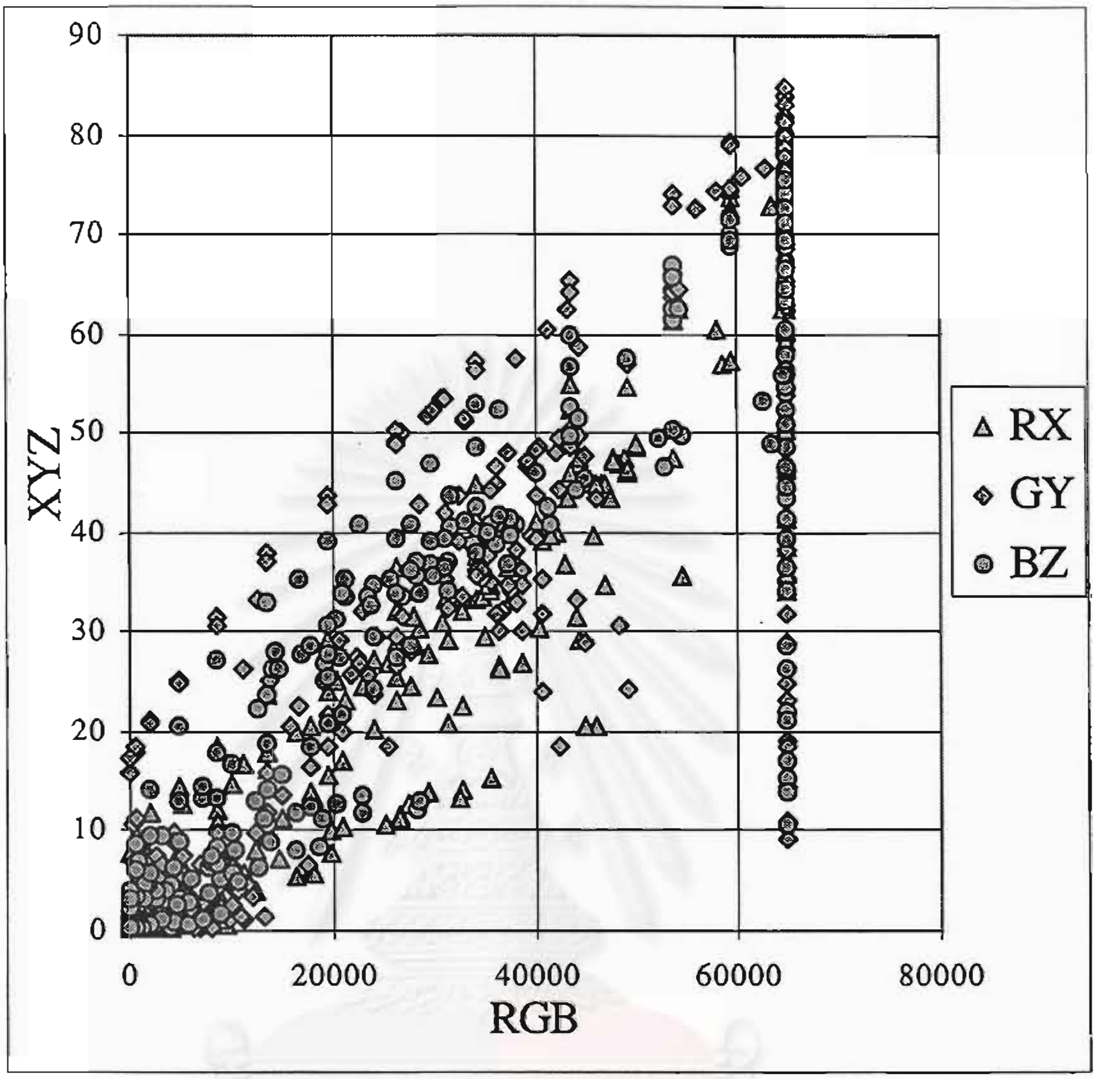


Figure 4-3 $R_mG_mB_m$ VS $X_pY_pZ_p$ with modification power by 2

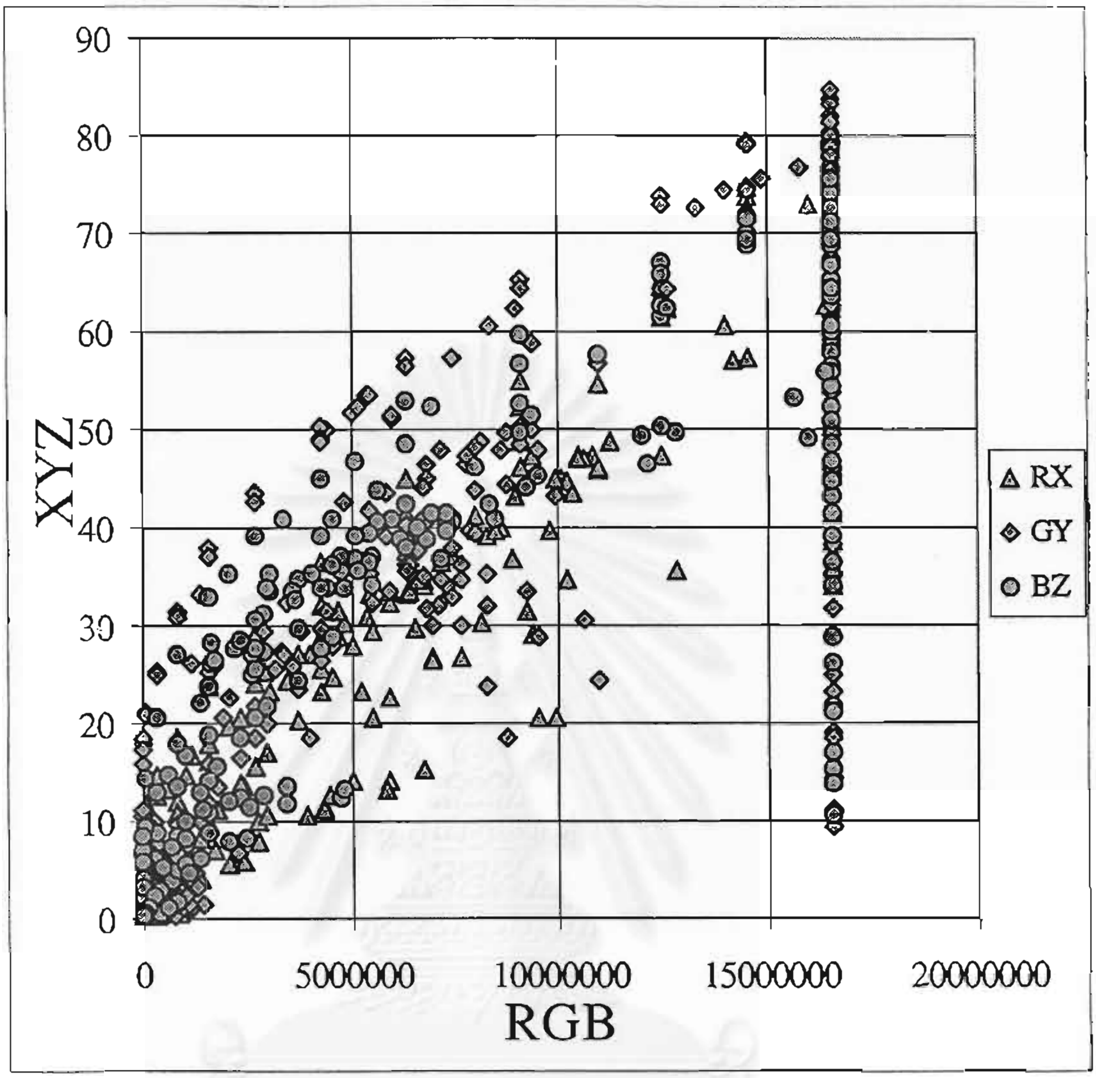


Figure 4-4 $R_m G_m B_m$ VS $X_p Y_p Z_p$ with modification power by 3

4.3 Regression

4.3.1 All the coefficients of each equation are listed in the table 4-1, 4-2, 4-3 and 4-4. The transformation by using the equation 3.2 can be called 3x4 matrix transformation. It is because there are 4 coefficients in the equation and 3 equations are needed to transform for each color, R, G, B. On the same way, the other equation can be called 3x8, 3x11 and 3x20 matrix transformation respectively.

4.3.2 The more terms are used, the more time and computing power are consumed. Unfortunately, there still was some coefficients are zero when the terms of the relation equation were increased, such as the a_{10}, a_{14}, a_{15} and a_{16} in the equation 3.5.

4.3.3 X_p, Y_p, Z_p values were substituted in the equation to check the printer characteristic. The R_{mp}, G_{mp}, B_{mp} were defined and plotted against X_p, Y_p, Z_p. The graphs were shown in the figure 4-5, 4-6, 4-7.

4.3.4 The same equations then were substituted by $X_0Y_0Z_0$ of the IT8.7 test target to calculate and print out the chart. After converted by equation 3.1, printed and measured, the $X_cY_cZ_c$ were plotted against $X_0Y_0Z_0$ and showed in the figure 4-8, 4-9, 4-10 and 4-11. The graphs show that the transformation is in very good linear relationship.

4.3.5 By the equation 2.4, the color different of the colors in IT8.7 and the print out were calculated. They all list in the table 4-5. It shows that more terms used in the equation, the average color different would be smaller.

The color different are high in some color and very low in many colors. The average color different are approximately 10 which still a little bit high. The partial colors were selected to do partial regression also. These selected colors were chosen from the colors with low color different. The sample colors were proceeded by the same way. The result of the color different by using 3x20 matrix are a little bit increase. Many factors which correlate to color different were studied also. The purpose is to decrease the color difference down. However, the decoding was not figured yet. It should be noted that the relationship between color different and the values of $(X^2+Y^2+Z^2)$ made some senses and hinted some correlation. It was shown in the figure 4-16. It shows that the more summations of X^2, Y^2, and Z^2 are, the less color different formed.

Table 4-1 Coefficients of equation 3.2

$P(x,y,z) = a_0+a_1x+a_2y+a_3z$

	R_{mc}	G_{mc}	B_{mc}
a_0	5404.497	4947.102	2818.742
a_1	1793.264	-1553.34	824.8311
a_2	-813.65	2186.586	-1352.08
a_3	-147.308	133.0823	1442.406

Table 4-2 Coefficients of equation 3.3

$P(x,y,z) = a_0+a_1x+a_2y+a_3z+a_4xy+a_5yz+a_6zx+a_7xyz$

	R_{mc}	G_{mc}	B_{mc}
a_0	2143.898	1551.869	622.6641
a_1	2329.879	-1422.93	903.9792
a_2	-574.657	2284.802	-1590.19
a_3	-274.758	618.3239	2105.396
a_4	-11.5692	-0.57938	5.608206
a_5	8.589973	-10.7708	-11.0586
a_6	-13.1996	-9.73911	-12.6227
$a_7(a_{10})$	0.095525	0.146071	0.146221

Table 4-3 Coefficients of equation 3.4

$$P(x,y,z) = a_0+a_1x+a_2y+a_3z+a_4xy+a_5yz+a_6zx+a_7x^2+a_8y^2+a_9z^2+a_{10}xyz$$

	R_{mc}	G_{mc}	B_{mc}
a_0	1974.029414	2378.45741	465.723934
a_1	2669.991445	-3060.247935	1429.166301
a_2	-918.434058	3918.050856	-2004.605525
a_3	-217.515106	231.97834	1967.000706
a_4	-15.722513	-119.663703	-104.38052
a_5	0.550337	-19.035492	-69.112579
a_6	-5.009757	-8.898193	35.938326
a_7	-5.810151	75.95749	24.285045
a_8	9.757766	45.918434	86.247096
a_9	-0.446652	8.210007	8.393532
a_{10}	0.091456	0.174667	0.162402

Table 4-4 Coefficients of equation 3.5

$$P(x,y,z) = a_0+a_1x+a_2y+a_3z+a_4xy+a_5yz+a_6zx+a_7x^2+a_8y^2+a_9z^2+a_{10}xyz$$
$$+a_{11}x^3+a_{12}y^3+a_{13}z^3+a_{14}xy^2+a_{15}x^2y+a_{16}yz^2+a_{17}y^2z+a_{18}z^2x+a_{19}zx$$

	R_{mc}	G_{mc}	B_{mc}
a_0	1776.147	2956.058	346.772
a_1	3110.166	-4279.85	1736.623
a_2	-1065.28	4753.588	-2859.97
a_3	-289.458	205.5339	2359.017
a_4	-4.77064	-101.022	-134.249
a_5	28.53413	4.441065	-141.879
a_6	-15.2754	-47.3182	74.60686
a_7	-20.6031	125.2902	11.80621
a_8	-4.30897	2.378026	160.5116
a_9	-8.73198	15.57921	14.36234
a_{11}	0.065349	-0.71189	0.326678
a_{12}	0.12482	0.407771	-0.65015
a_{13}	0.074537	-0.04051	-0.02681
a_{17}	-0.25291	-0.25031	0.866429
a_{18}	-0.01185	-0.08367	-0.01267
a_{19}	0.167947	0.696773	-0.36185

When a_{10}, a_{14}, a_{15} and a_{16} are omitable.

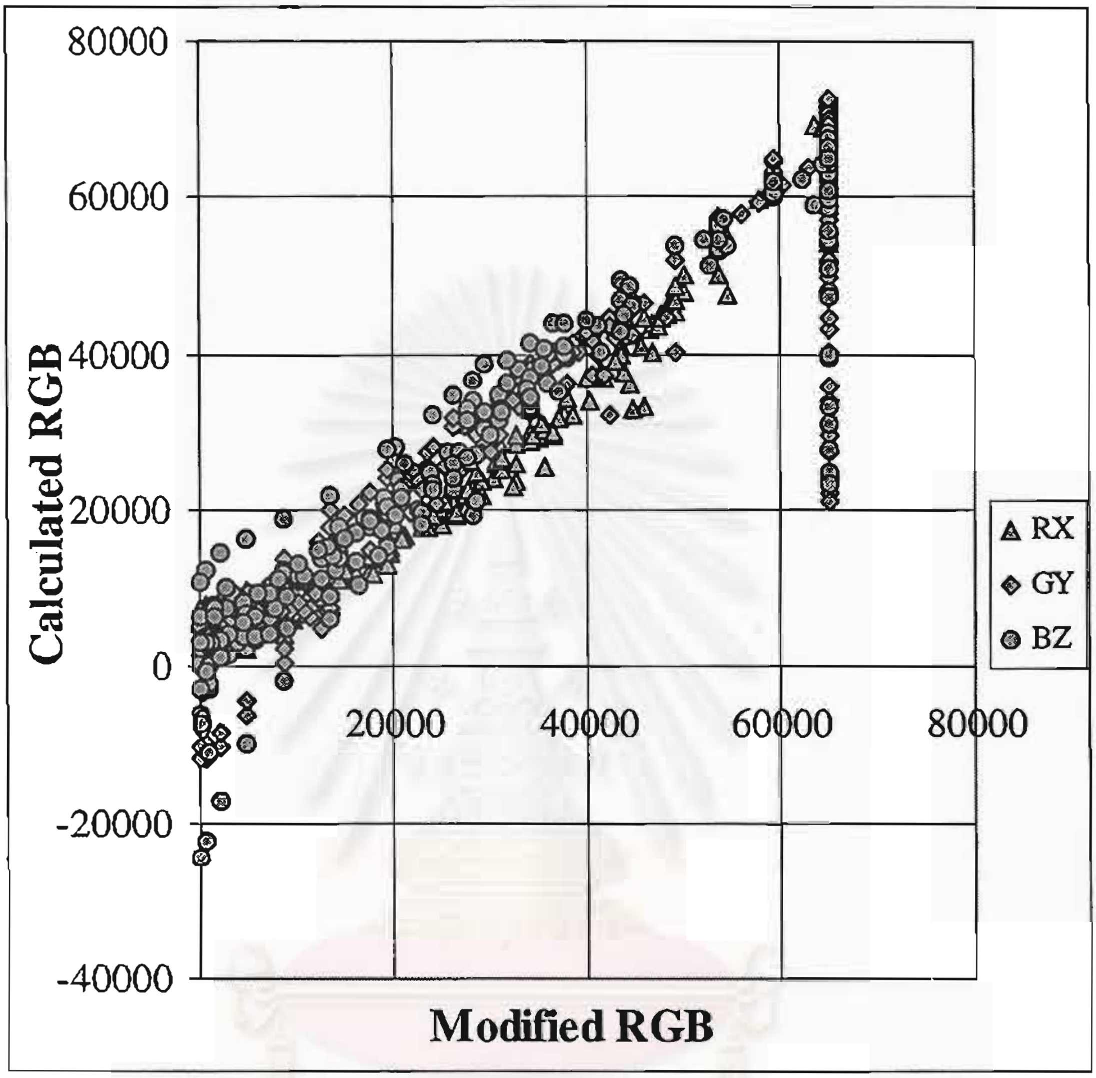


Figure 4-5 $R_mG_mB_m$ values plotted to RGB values which were calculated from the $X_pY_pZ_p$ by using 3x4 (equation 3.2) transformation

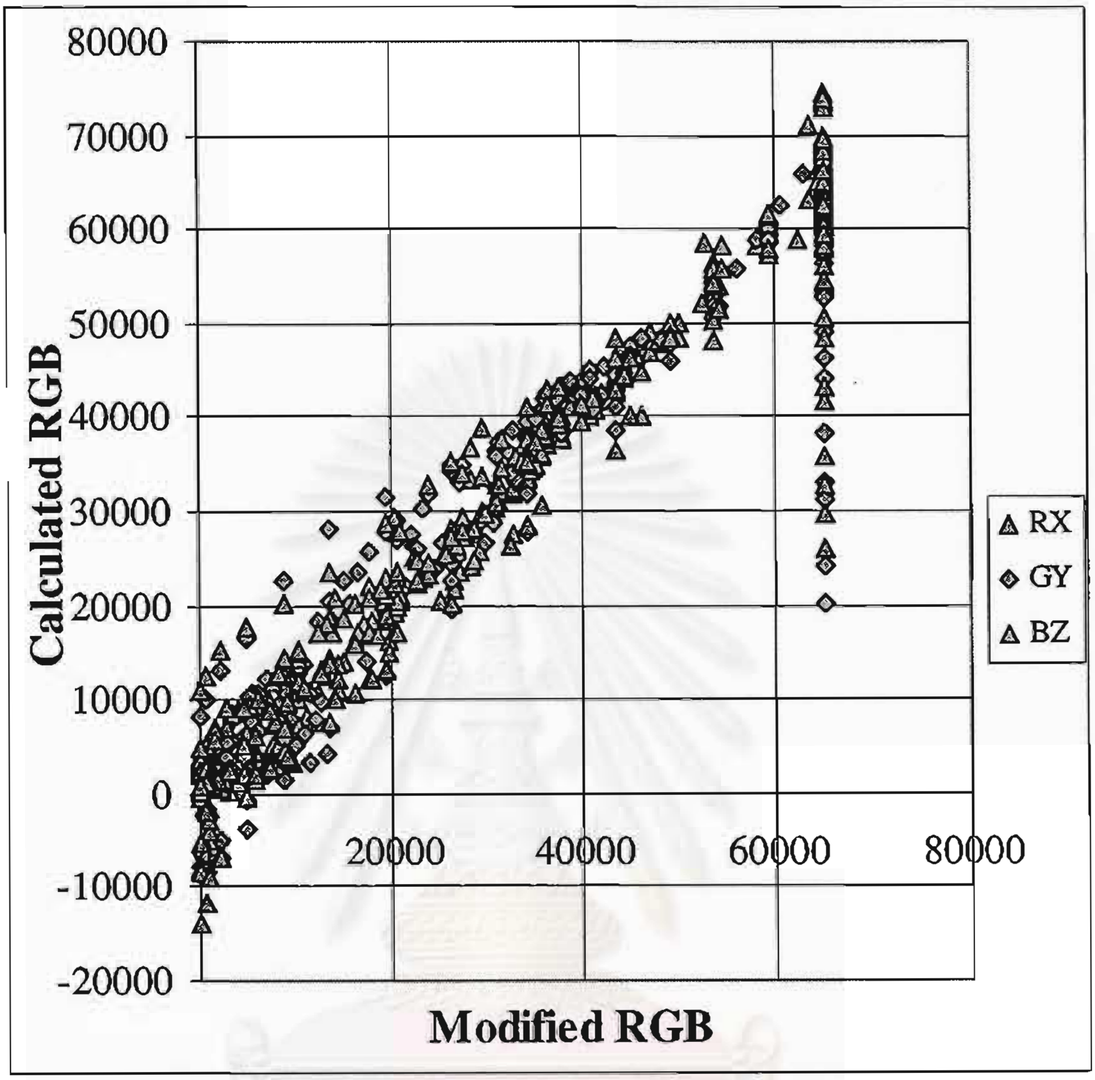


Figure 4-6 $R_m G_m B_m$ values plotted to RGB values which were calculated from the $X_p Y_p Z_p$ by using 3x8 (equation 3.3) transformation

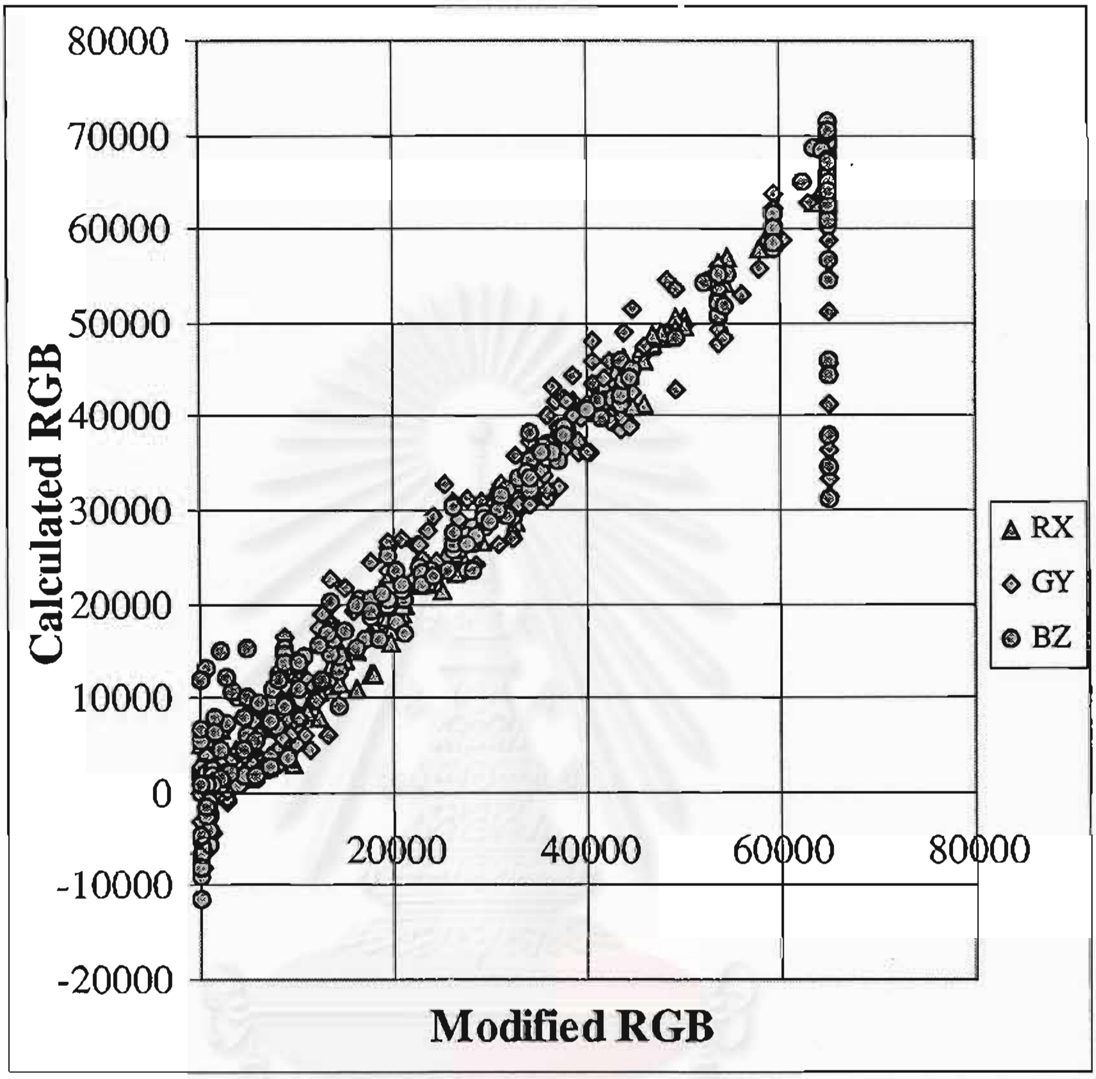


Figure 4-7 $R_mG_mB_m$ values plotted to RGB values which were calculated from the $X_pY_pZ_p$ by using 3x11 (equation 3.4) transformation

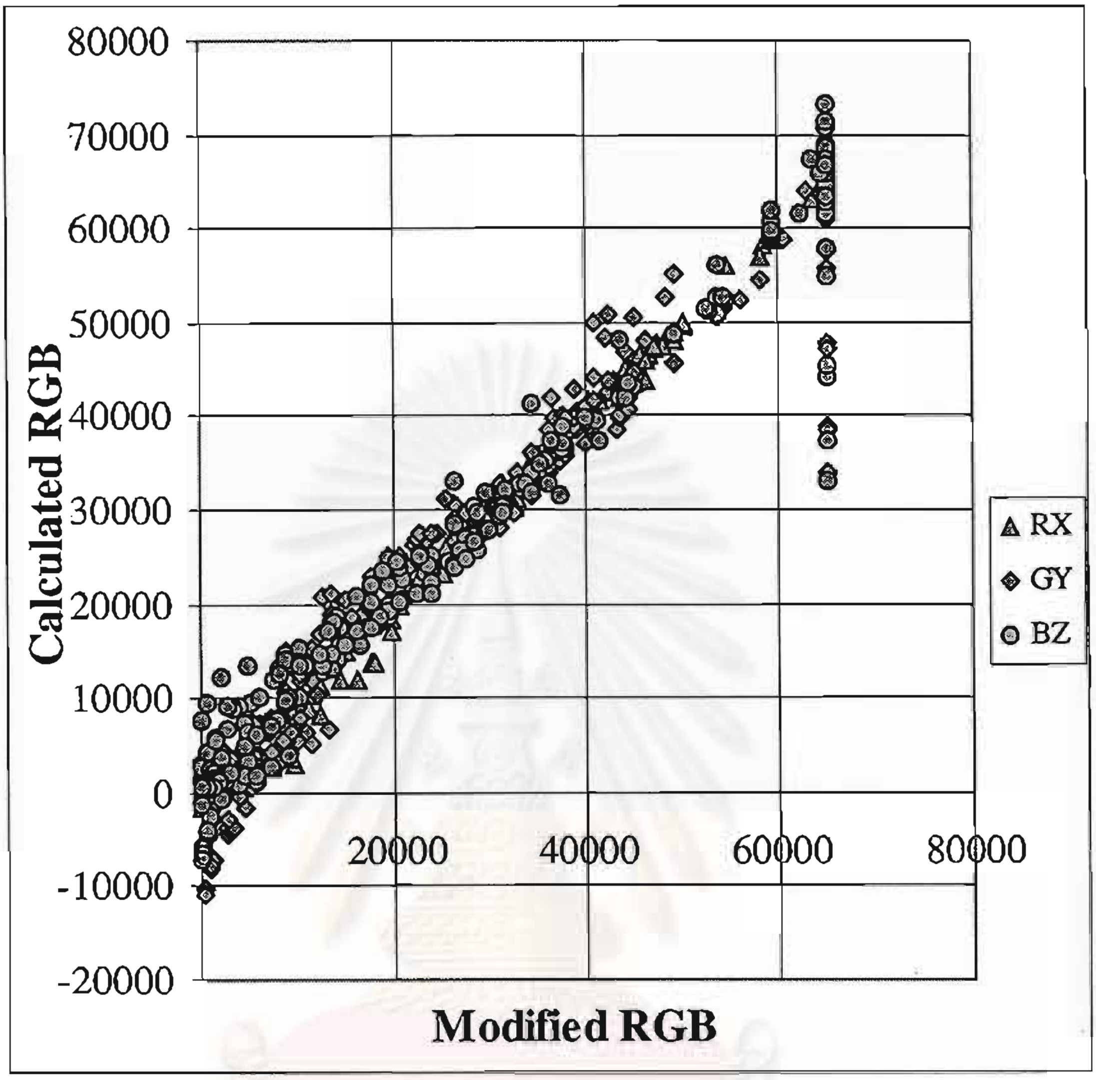


Figure 4-8 $R_mG_mB_m$ values plotted to RGB values which were calculated from the $X_pY_pZ_p$ by using 3x20 (equation 3.5) transformation

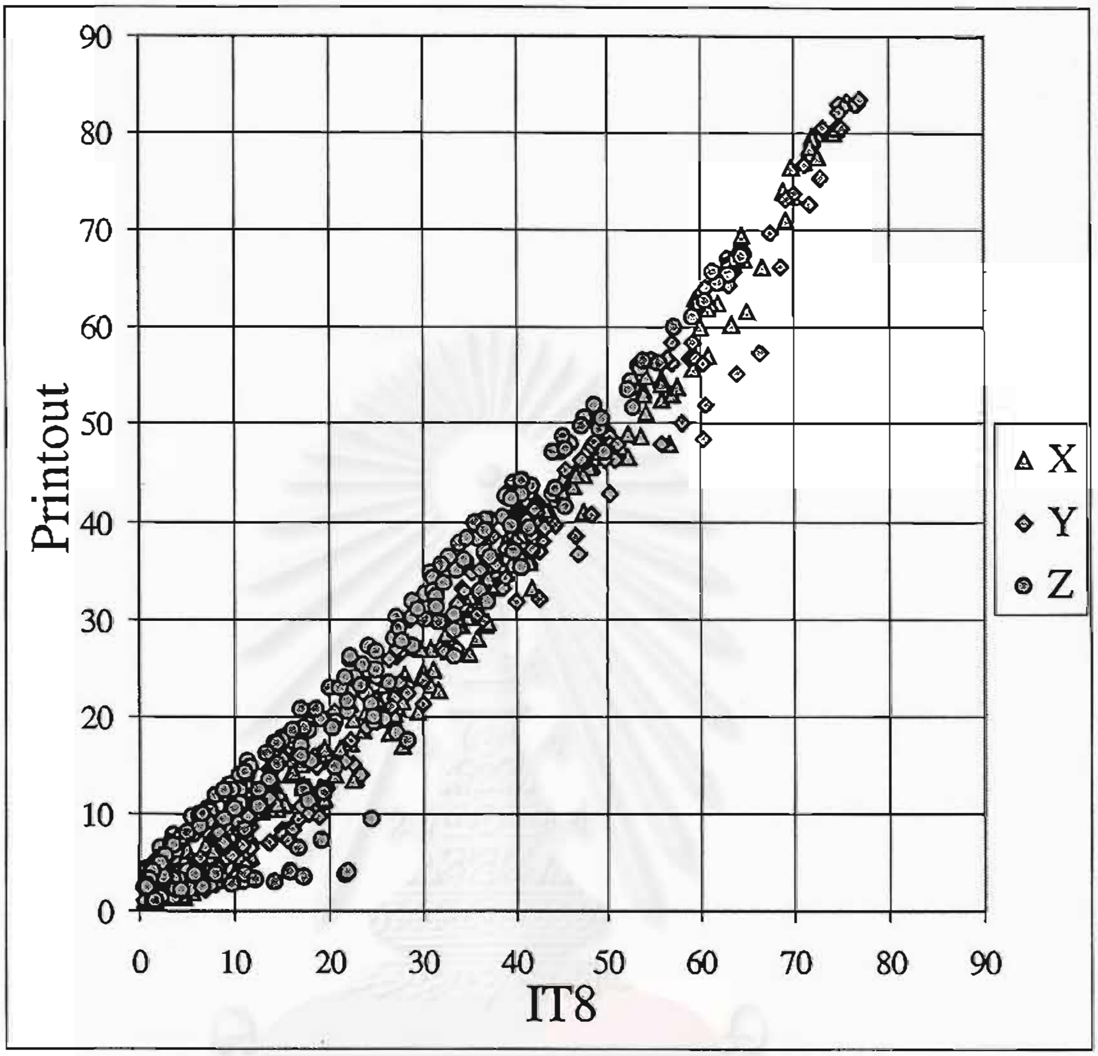


Figure 4-9 XYZ color values comparison between original IT8 VS printout using 3x4 (equation 3.2) transformation

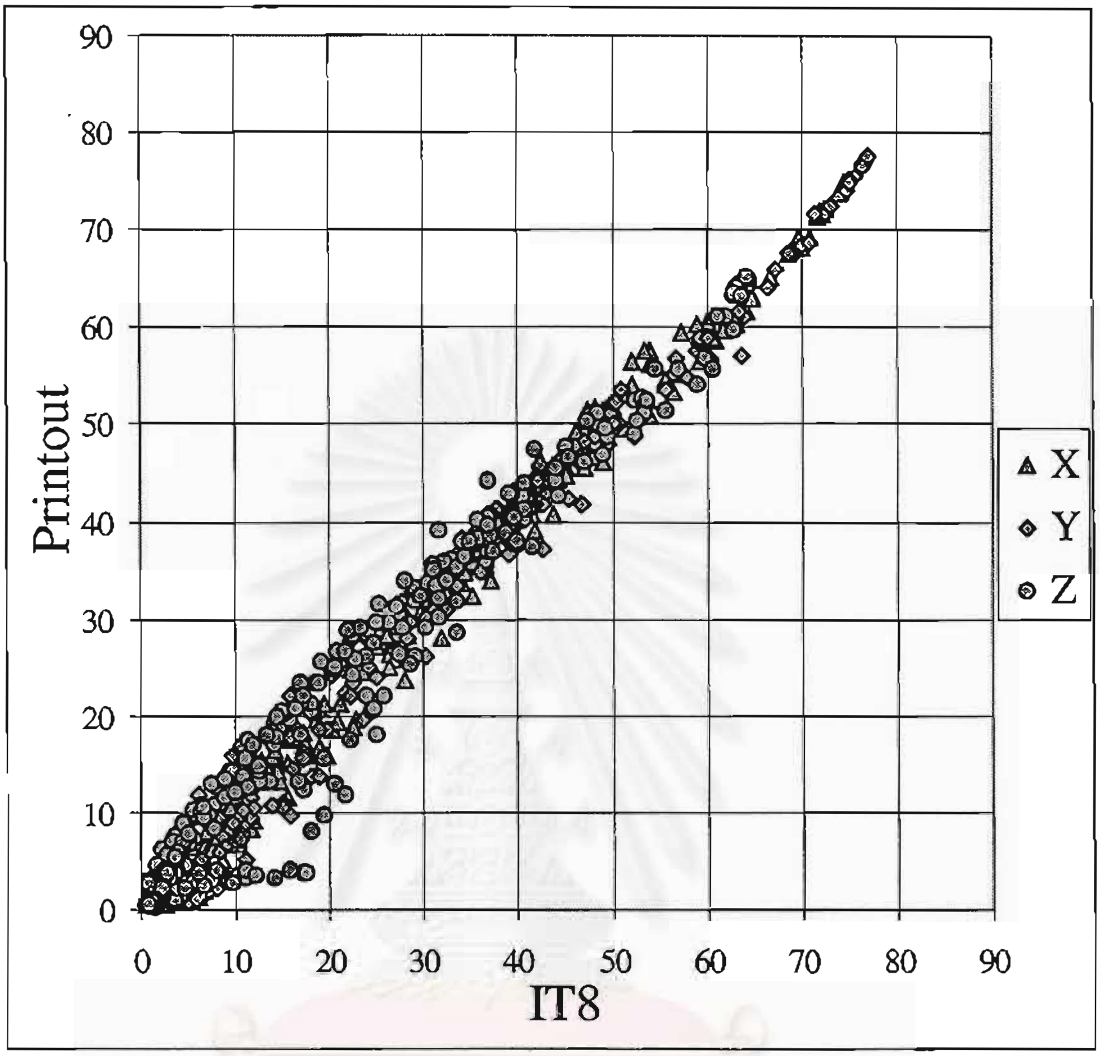


Figure 4-10 XYZ color values comparison between original IT8 VS printout using 3x8 (equation 3.3) transformation

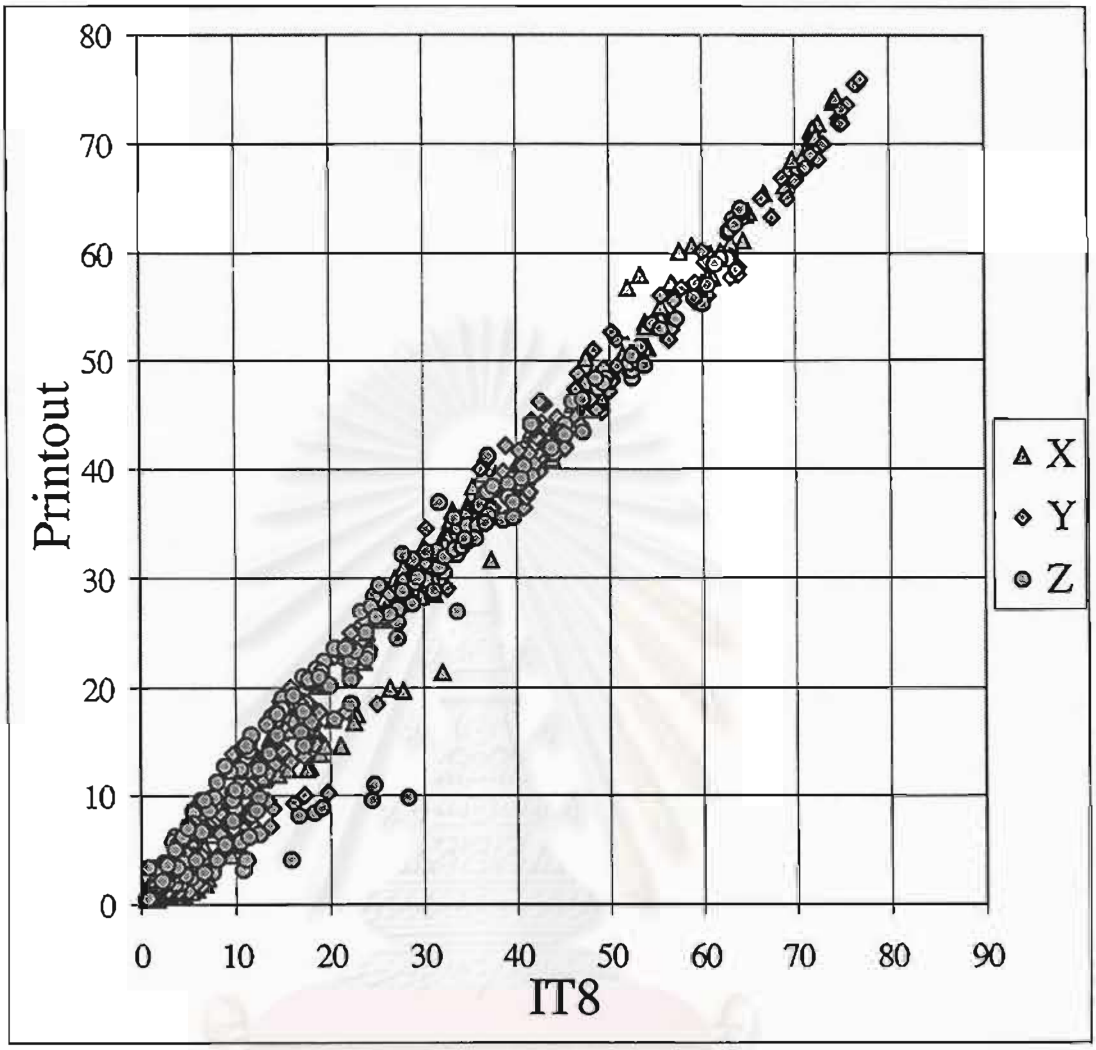


Figure 4-11 XYZ color values comparison between original IT8 VS printout using 3x11 (equation 3.4) transformation

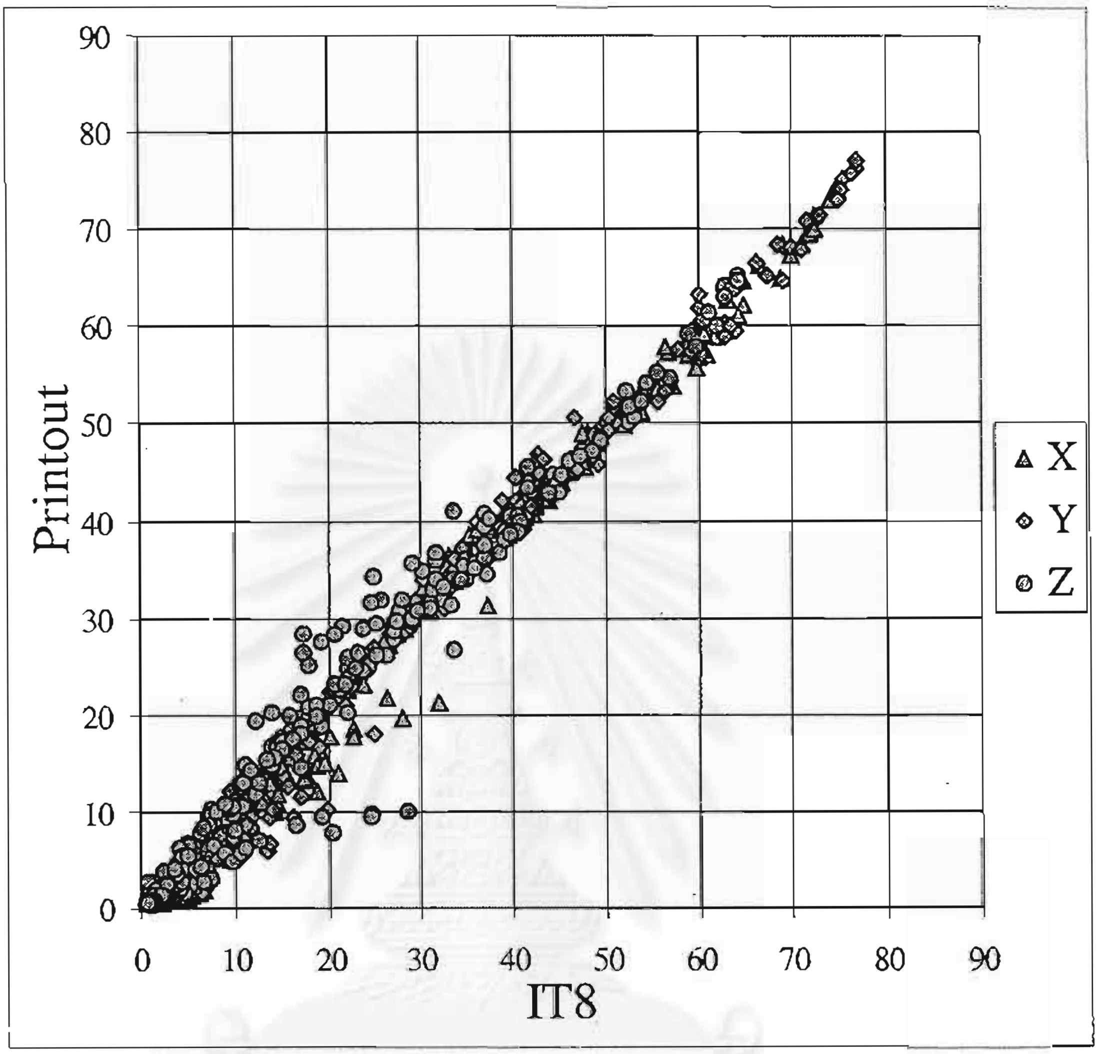


Figure 4-12 XYZ color values comparison between original IT8 VS printout using 3x20 (equation 3.5) transformation

Table 4-5 The color different of each matrix.

Matrix	Average	Max.	Min.
3x4	15.7567	48.9684	1.40018
3x8	13.2826	43.1525	0.25318
3x11	11.0222	37.5486	0.38079
3x20	9.37042	30.5288	0.41533

The standard test chart IT8 was sent to the Procedure to transform and the print out were shown in the Figure 4-13

On the same way, the standard images were used to test the process as well, and their results are shown in the Figure 4-14 and 4-15.

Their print out show that the detail of the image incease when more term are used to do transformation. The improvement apear specially in shadow and middle tone region and improve the red area contrast also.

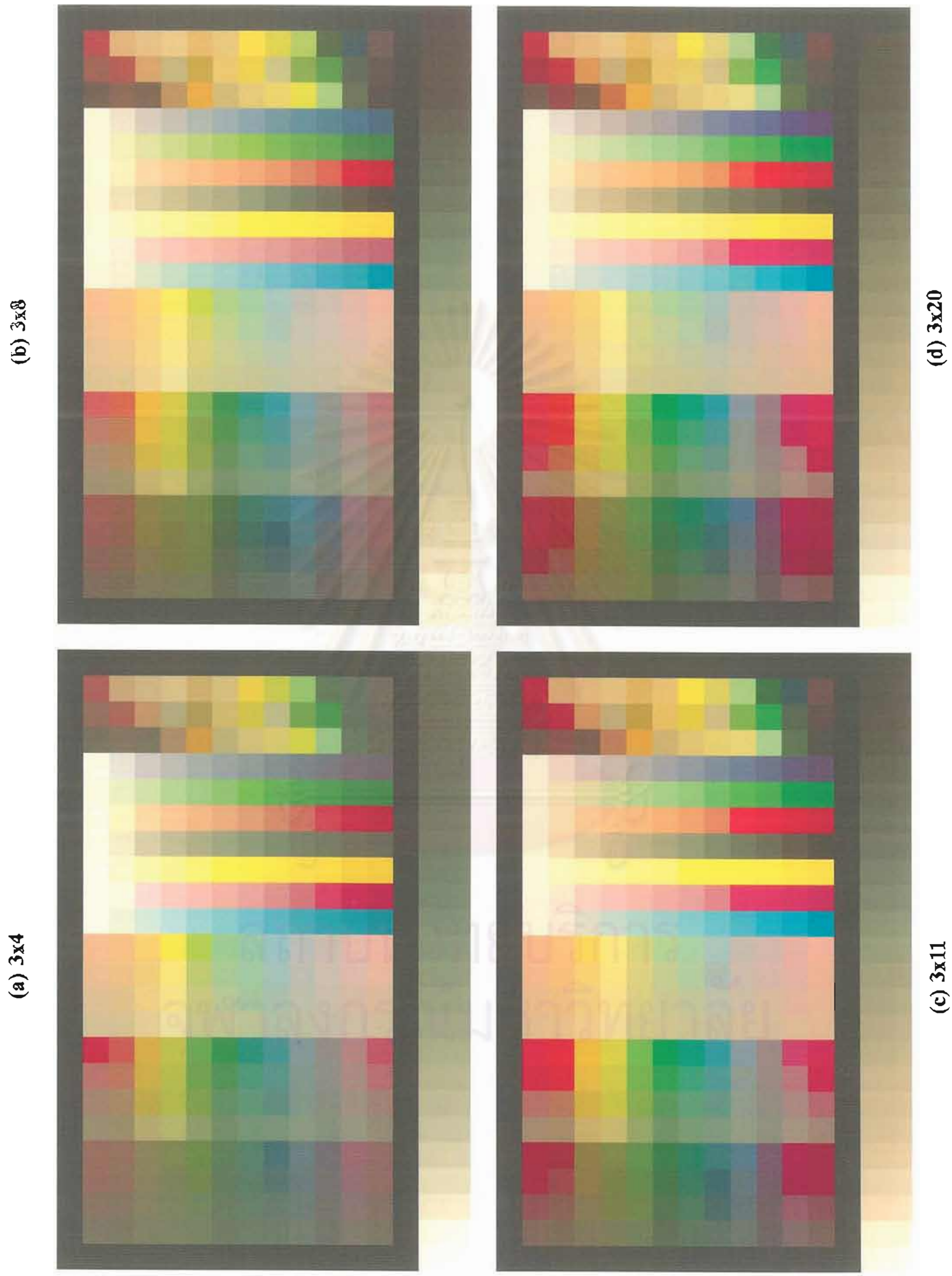


Figure 4-13 The printouts of the IT8 test chart when transform by each equation

(a) 3x4 **(b) 3x8**

(c) 3x11 **(d) 3x20**

Figure 4-14 The printouts of the standard color image, Bride that shows screen tone color, when transform by each equation

(b) 3x8

(d) 3x20

(a) 3x4

(c) 3x11

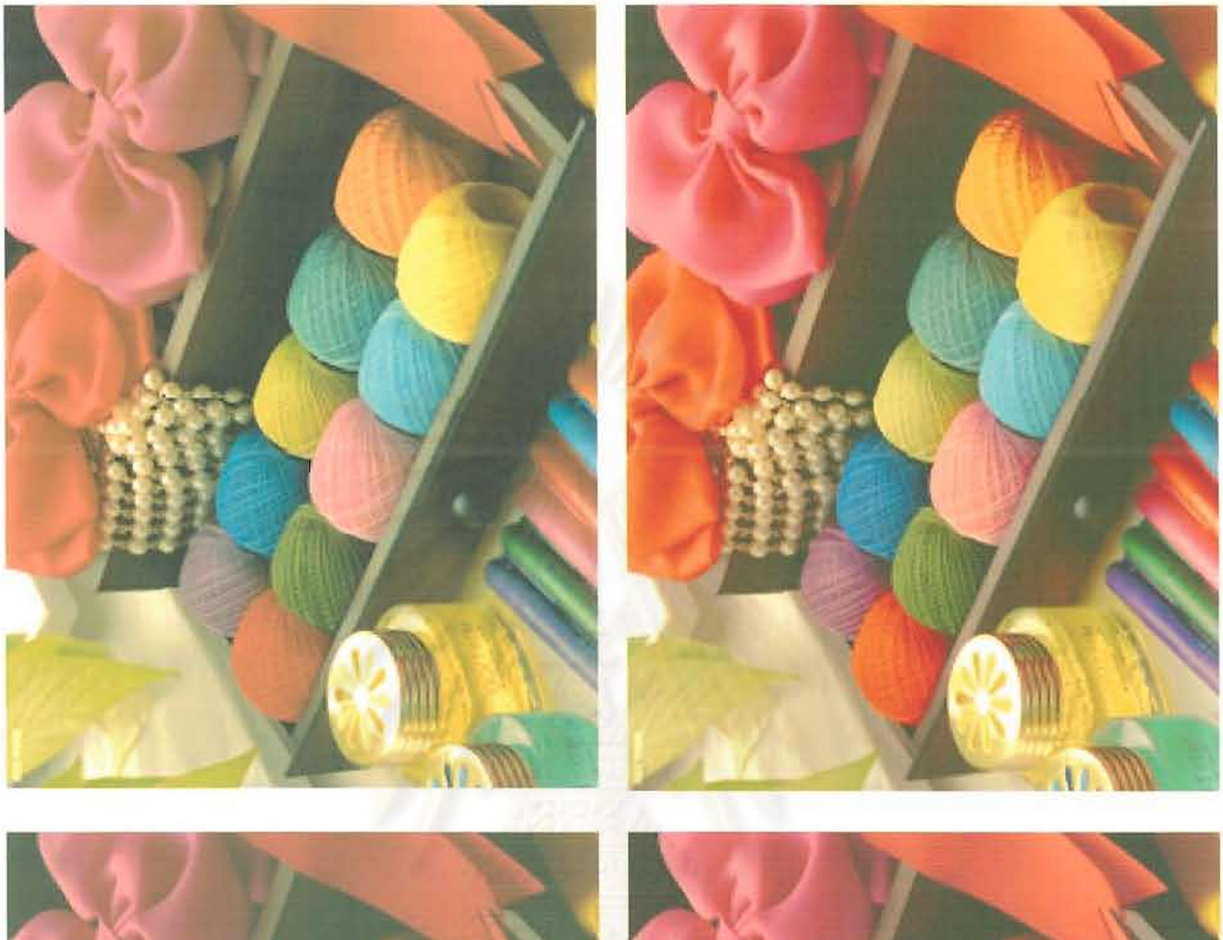


Figure 4-15 The printouts of the standard color image, Wool that shows saturated colors, when transform by each equation

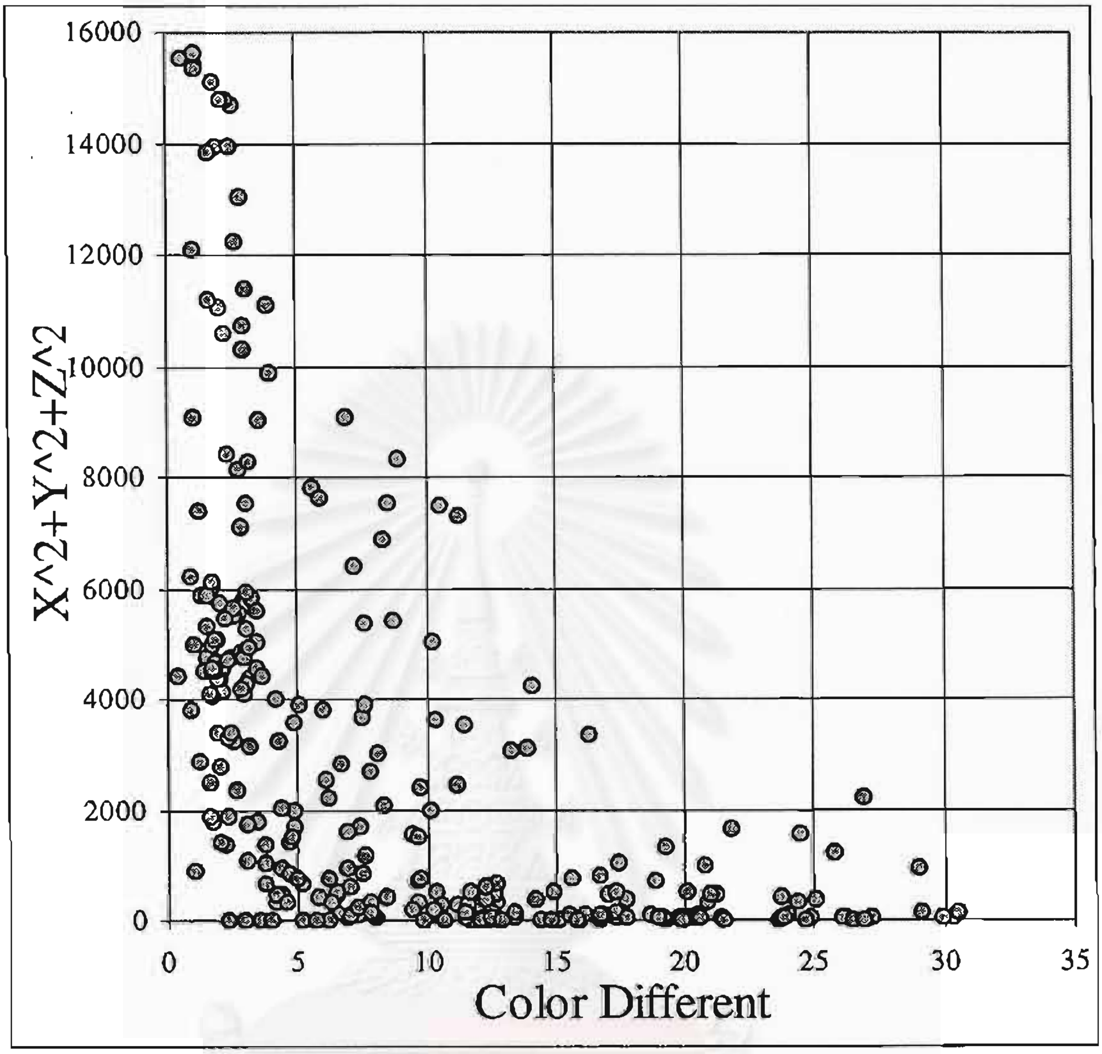


Figure 4-16 $X^2Y^2Z^2$ and color different relationship

4.4 END

4.4.1 The table 4-6 shows the list of the CMY color values besides the K values that produced the lowest color different. The color different of them are included next also. Figure 4-17 shows the END graph. The result shows that the colors of ink which used in the research are extremely well prepared by the factory. The colors' values of CMY with nearly the same amount can be mixed to produce the same color values of K with the same amount. For example, the mixture of 30% of C, M, and Y shows the same color value, Lab, as 30% of K.

4.4.2 The NewC, NewM, NewY and NewK were defined by the subroutine LUT to compare its color values to the original, IT8.7 test target. The color different of each equation after applied NewK were calculated and found that they were increased a little. It is confident to assume that the color values before and after apply black to the color patch are a little bit higher.

table 4-6 the list of the CMY color values beside the K values

C	M	Y	K	ΔE^*_{ab}
0	0	0	0	0
5	5	5	5	0.3617
10	10	10	10	0.779
15	15	17	15	0.1626
20	20	22	20	0.3076
25	25	27	25	0.5992
30	30	30	30	0.6625
35	35	35	35	0.2564
40	40	42	40	0.6338
45	45	45	45	0.4385
50	50	50	50	0.1456
55	55	55	55	0.3185
60	60	60	60	0.1317
65	65	65	65	0.2793
68	70	70	70	1.4585
71	75	73	75	0.6002
78	80	80	80	0.3069
83	85	85	85	0.4251
88	90	90	90	2.8518
95	95	95	95	0.2725
98	100	98	100	0.2786

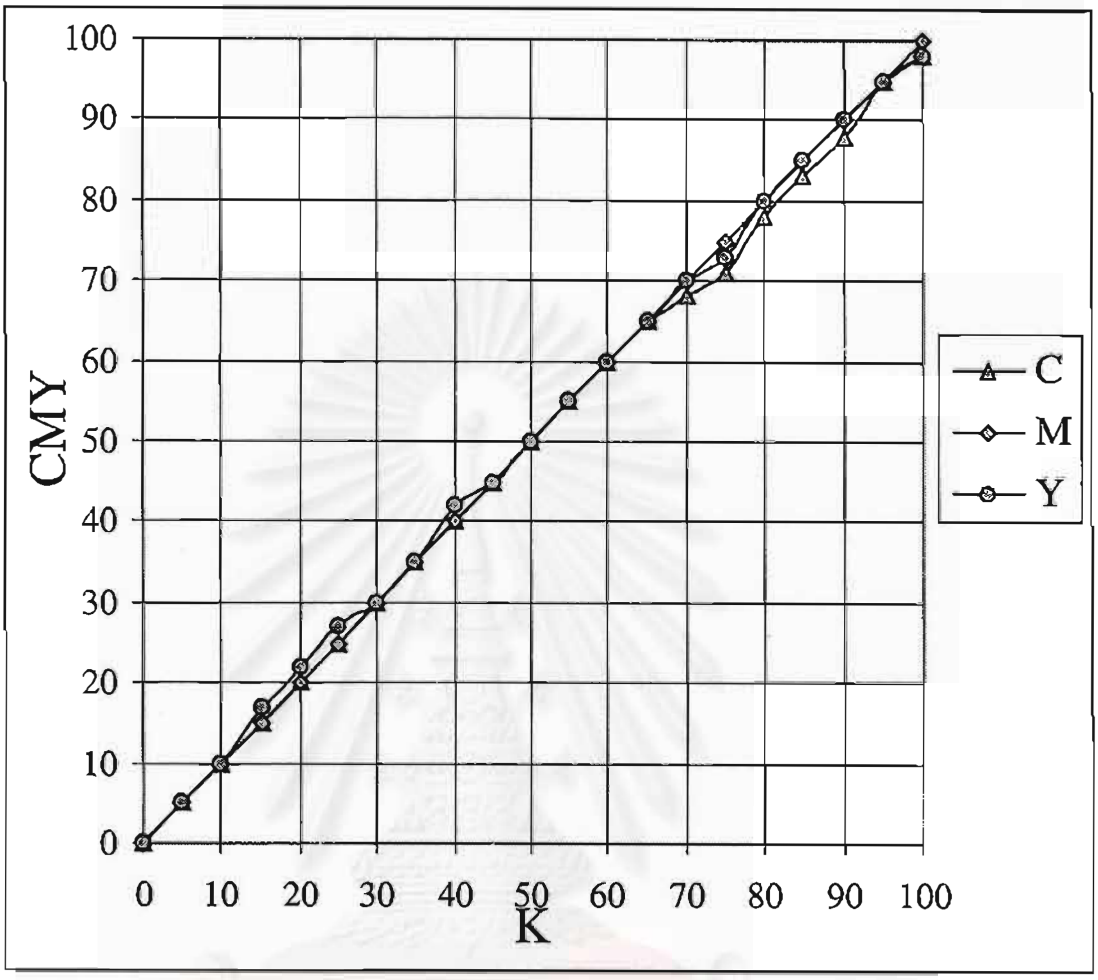


Figure 4-17 The END Graph

CHAPTER 5

CONCLUSION AND SUGGESTION

5.1 Conclusion

There are many techniques to do color transformation including color definition, non-linear function, linear regression, linear interpolation, 3D look up table, etc. Moreover, the combination techniques can be employed. This gives varieties of techniques for transforming the color spaces. In the research, the combination techniques were used also. The color definition is the simplest process but cannot produce the correct transformation. However, this technique can be used for other purposes. For example, in the research, it was used to transform RGB to CMY at the first process. The objective to use this technique rather than other complex technique is that;

1. It is the simplest technique.
2. The process can be controlled.
3. The equation can be easily adjusted such as that in equation 3.1.

The adjusting the maximum ink to the equation shows the effect to the color gamut. The RGB correction is a form of non-linear transformation. This technique is the same as the first technique. It transforms only one color at a time. So, it cannot product the correct transformation as well. Unfortunately, these techniques were used for other purpose. They were used for modifying the RGB values to the new ones which gave easier and better result for the regression technique. The regression technique is the technique that concerns all the colors. This accompanies with the impurities of the primary colors of ink. The coefficients can be find by many programs such as SPSS, Mathametica, Mathlab. More terms of regression produce better result of transformation. However, it is not confident to say that this technique can produce better result by increasing more terms.

To find the END of color, the colorimetric values can be the powerful tool for evaluating and judging. The inks in the research are very well prepared by the factory. It shows the balance of the color mixture very well. The use of the black printer LUT in the subroutine can change only slightly difference in color.

5.2 Suggestion

The color different in the research are around 10 which is not a good result. However, this technique is an easy technique. There are many combination techniques that have not been used. For example, the partial regression should improve the result.

In the research used Standard test chart, IT 8.7 which consisted of 288 colors. This is still small number of colors patches. To get better result, more colors patches should be applied for the experiment.

To discover the relationship of the color different to other color values can determine the problem of the transformation error. After that, the problem can be solved.

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APPENDICES

APPENDIX A

IT8.7 Reference RGB data

Date: 11/14/1997 Time: 11:03

BEGIN_DATA_FORMAT

Sample_Name RGB_R RGB_G RGB_B

END_DATA_FORMAT

BEGIN_DATA

A1	46.00	12.00	11.00
A2	64.00	0.00	3.00
A3	84.00	0.00	0.00
A4	97.00	0.00	3.00
A5	127.00	71.00	71.00
A6	158.00	51.00	63.00
A7	181.00	32.00	58.00
A8	215.00	14.00	52.00
A9	221.00	190.00	182.00
A10	242.00	182.00	178.00
A11	255.00	175.00	172.00
A12	255.00	164.00	168.00
A13	244.00	255.00	255.00
A14	255.00	244.00	255.00
A15	255.00	255.00	244.00
A16	244.00	244.00	244.00
A17	255.00	244.00	244.00
A18	244.00	255.00	244.00
A19	244.00	244.00	255.00
A20	207.00	165.00	143.00
A21	195.00	194.00	172.00
A22	187.00	164.00	138.00

B1	42.00	15.00	4.00
B2	58.00	6.00	0.00
B3	82.00	3.00	0.00
B4	85.00	1.00	0.00
B5	133.00	69.00	51.00
B6	163.00	52.00	24.00
B7	189.00	36.00	2.00
B8	212.00	24.00	0.00
B9	224.00	193.00	176.00
B10	244.00	182.00	168.00
B11	255.00	176.00	155.00
B12	255.00	171.00	142.00
B13	232.00	255.00	255.00
B14	255.00	232.00	255.00
B15	255.00	255.00	232.00
B16	232.00	232.00	232.00
B17	255.00	232.00	232.00
B18	232.00	255.00	232.00
B19	232.00	232.00	255.00
B20	219.00	201.00	172.00
B21	220.00	200.00	160.00
B22	216.00	198.00	153.00
C1	54.00	37.00	12.00
C2	61.00	29.00	0.00
C3	75.00	33.00	0.00
C4	75.00	30.00	0.00
C5	181.00	128.00	85.00

C6	211.00	117.00	36.00
C7	234.00	106.00	0.00
C8	255.00	112.00	0.00
C9	241.00	211.00	178.00
C10	255.00	208.00	166.00
C11	255.00	203.00	145.00
C12	255.00	195.00	119.00
C13	209.00	255.00	255.00
C14	255.00	209.00	255.00
C15	255.00	255.00	209.00
C16	209.00	209.00	209.00
C17	255.00	209.00	209.00
C18	209.00	255.00	209.00
C19	209.00	209.00	255.00
C20	194.00	176.00	138.00
C21	217.00	190.00	166.00
C22	218.00	189.00	130.00
D1	42.00	40.00	12.00
D2	46.00	39.00	0.00
D3	52.00	42.00	0.00
D4	52.00	42.00	0.00
D5	174.00	153.00	100.00
D6	191.00	149.00	55.00
D7	197.00	147.00	0.00
D8	210.00	156.00	0.00
D9	252.00	237.00	191.00
D10	255.00	241.00	172.00

D11	255.00	246.00	150.00
D12	255.00	251.00	128.00
D13	185.00	255.00	255.00
D14	255.00	185.00	255.00
D15	255.00	255.00	185.00
D16	185.00	185.00	185.00
D17	255.00	185.00	185.00
D18	185.00	255.00	185.00
D19	185.00	185.00	255.00
D20	219.00	206.00	145.00
D21	222.00	198.00	120.00
D22	214.00	176.00	112.00
E1	26.00	41.00	12.00
E2	20.00	40.00	0.00
E3	21.00	49.00	0.00
E4	20.00	48.00	0.00
E5	94.00	107.00	66.00
E6	90.00	109.00	27.00
E7	75.00	106.00	0.00
E8	74.00	114.00	0.00
E9	186.00	195.00	164.00
E10	189.00	199.00	154.00
E11	189.00	200.00	133.00
E12	193.00	215.00	118.00
E13	162.00	255.00	255.00
E14	255.00	162.00	255.00
E15	255.00	255.00	162.00

E16	162.00	162.00	162.00
E17	255.00	162.00	162.00
E18	162.00	255.00	162.00
E19	162.00	162.00	255.00
E20	208.00	212.00	144.00
E21	162.00	192.00	155.00
E22	171.00	194.00	139.00
F1	0.00	14.00	1.00
F2	0.00	21.00	1.00
F3	0.00	24.00	1.00
F4	0.00	23.00	1.00
F5	20.00	78.00	53.00
F6	0.00	82.00	41.00
F7	0.00	80.00	25.00
F8	0.00	90.00	22.00
F9	175.00	197.00	177.00
F10	167.00	202.00	176.00
F11	153.00	210.00	173.00
F12	133.00	220.00	169.00
F13	139.00	255.00	255.00
F14	255.00	139.00	255.00
F15	255.00	255.00	139.00
F16	139.00	139.00	139.00
F17	255.00	139.00	139.00
F18	139.00	255.00	139.00
F19	139.00	139.00	255.00
F20	87.00	132.00	31.00

F21	134.00	159.00	31.00
F22	205.00	206.00	120.00
G1	0.00	29.00	19.00
G2	0.00	31.00	21.00
G3	0.00	41.00	32.00
G4	0.00	40.00	30.00
G5	27.00	96.00	87.00
G6	0.00	99.00	87.00
G7	0.00	99.00	88.00
G8	0.00	104.00	94.00
G9	167.00	197.00	184.00
G10	151.00	202.00	185.00
G11	127.00	212.00	190.00
G12	100.00	222.00	193.00
G13	116.00	255.00	255.00
G14	255.00	116.00	255.00
G15	255.00	255.00	116.00
G16	116.00	116.00	116.00
G17	255.00	116.00	116.00
G18	116.00	255.00	116.00
G19	116.00	116.00	255.00
G20	201.00	143.00	85.00
G21	191.00	150.00	31.00
G22	177.00	125.00	31.00
H1	0.00	26.00	30.00
H2	0.00	25.00	39.00
H3	0.00	34.00	56.00

H4	0.00	34.00	57.00
H5	27.00	94.00	100.00
H6	0.00	93.00	112.00
H7	0.00	96.00	127.00
H8	0.00	91.00	136.00
H9	159.00	195.00	195.00
H10	145.00	197.00	204.00
H11	106.00	202.00	230.00
H12	71.00	206.00	252.00
H13	93.00	255.00	255.00
H14	255.00	93.00	255.00
H15	255.00	255.00	93.00
H16	93.00	93.00	93.00
H17	255.00	93.00	93.00
H18	93.00	255.00	93.00
H19	93.00	93.00	255.00
H20	232.00	205.00	31.00
H21	217.00	151.00	31.00
H22	171.00	66.00	40.00
I1	0.00	38.00	54.00
I2	0.00	35.00	72.00
I3	0.00	32.00	83.00
I4	0.00	29.00	94.00
I5	75.00	101.00	116.00
I6	57.00	101.00	133.00
I7	32.00	103.00	151.00
I8	0.00	100.00	168.00

I9	175.00	189.00	195.00
I10	169.00	193.00	212.00
I11	155.00	190.00	234.00
I12	142.00	191.00	255.00
I13	70.00	255.00	255.00
I14	255.00	70.00	255.00
I15	255.00	255.00	70.00
I16	70.00	70.00	70.00
I17	255.00	70.00	70.00
I18	70.00	255.00	70.00
I19	70.00	70.00	255.00
I20	165.00	66.00	39.00
I21	134.00	63.00	39.00
I22	96.00	63.00	33.00
J1	0.00	8.00	26.00
J2	0.00	6.00	47.00
J3	0.00	4.00	63.00
J4	0.00	4.00	76.00
J5	73.00	84.00	101.00
J6	66.00	78.00	117.00
J7	68.00	77.00	137.00
J8	59.00	73.00	151.00
J9	181.00	186.00	194.00
J10	181.00	186.00	210.00
J11	176.00	185.00	232.00
J12	167.00	181.00	254.00
J13	46.00	255.00	255.00

J14	255.00	46.00	255.00
J15	255.00	255.00	46.00
J16	46.00	46.00	46.00
J17	255.00	46.00	46.00
J18	46.00	255.00	46.00
J19	46.00	46.00	255.00
J20	39.00	68.00	75.00
J21	76.00	45.00	50.00
J22	41.00	64.00	50.00
K1	41.00	27.00	50.00
K2	56.00	13.00	66.00
K3	63.00	0.00	76.00
K4	74.00	0.00	84.00
K5	105.00	93.00	114.00
K6	120.00	83.00	127.00
K7	140.00	72.00	142.00
K8	144.00	56.00	169.00
K9	195.00	185.00	194.00
K10	202.00	180.00	203.00
K11	215.00	176.00	229.00
K12	224.00	169.00	250.00
K13	23.00	255.00	255.00
K14	255.00	23.00	255.00
K15	255.00	255.00	23.00
K16	23.00	23.00	23.00
K17	255.00	23.00	23.00
K18	23.00	255.00	23.00

K19	23.00	23.00	255.00
K20	55.00	84.00	38.00
K21	83.00	62.00	33.00
K22	46.00	72.00	38.00
L1	39.00	13.00	21.00
L2	56.00	0.00	21.00
L3	75.00	0.00	31.00
L4	85.00	0.00	39.00
L5	111.00	74.00	90.00
L6	140.00	53.00	93.00
L7	163.00	30.00	100.00
L8	180.00	14.00	103.00
L9	204.00	185.00	190.00
L10	222.00	180.00	189.00
L11	254.00	173.00	191.00
L12	255.00	162.00	194.00
L13	0.00	255.00	255.00
L14	255.00	0.00	255.00
L15	255.00	255.00	0.00
L16	0.00	0.00	0.00
L17	255.00	0.00	0.00
L18	0.00	255.00	0.00
L19	0.00	0.00	255.00
L20	39.00	36.00	31.00
L21	50.00	39.00	32.00
L22	40.00	33.00	33.00
GS0	255.00	255.00	255.00

GS1	244.00	244.00	244.00
GS2	233.00	233.00	233.00
GS3	222.00	222.00	222.00
GS4	211.00	211.00	211.00
GS5	200.00	200.00	200.00
GS6	188.00	188.00	188.00
GS7	177.00	177.00	177.00
GS8	166.00	166.00	166.00
GS9	155.00	155.00	155.00
GS10	144.00	144.00	144.00
GS11	133.00	133.00	133.00
GS12	122.00	122.00	122.00
GS13	111.00	111.00	111.00
GS14	100.00	100.00	100.00
GS15	89.00	89.00	89.00
GS16	78.00	78.00	78.00
GS17	67.00	67.00	67.00
GS18	55.00	55.00	55.00
GS19	44.00	44.00	44.00
GS20	33.00	33.00	33.00
GS21	22.00	22.00	22.00
GS22	11.00	11.00	11.00
GS23	0.00	0.00	0.00

END_DATA

APPENDIX B

The example of finding coefficients of the regression

For the equation $P(x,y,z) = a_1x+a_2y+a_3z+a_4xy+a_5yz+a_6zx$

where a is the vector of the coefficients and p is the vector of dependent variables.

$$V = \begin{bmatrix} x_1 & x_2 & x_3 & x_4 & x_5 & x_6 & x_7 & x_8 \\ y_1 & y_2 & y_3 & y_4 & y_5 & y_6 & y_7 & y_8 \\ z_1 & z_2 & z_3 & z_4 & z_5 & z_6 & z_7 & z_8 \\ x_1y_1 & x_2y_2 & x_3y_3 & x_4y_4 & x_5y_5 & x_6y_6 & x_7y_7 & x_8y_8 \\ y_1z_1 & y_2z_2 & y_3z_3 & y_4z_4 & y_5z_5 & y_6z_6 & y_7z_7 & y_8z_8 \\ z_1x_1 & z_2x_2 & z_3x_3 & z_4x_4 & z_5x_5 & z_6x_6 & z_7x_7 & z_8x_8 \end{bmatrix}$$

$$V' = \begin{bmatrix} x_1 & y_1 & z_1 & x_1y_1 & y_1z_1 & z_1x_1 \\ x_2 & y_2 & z_2 & x_2y_2 & y_2z_2 & z_2x_2 \\ x_3 & y_3 & z_3 & x_3y_3 & y_3z_3 & z_3x_3 \\ x_4 & y_4 & z_4 & x_4y_4 & y_4z_4 & z_4x_4 \\ x_5 & y_5 & z_5 & x_5y_5 & y_5z_5 & z_5x_5 \\ x_6 & y_6 & z_6 & x_6y_6 & y_6z_6 & z_6x_6 \\ x_7 & y_7 & z_7 & x_7y_7 & y_7z_7 & z_7x_7 \\ x_8 & y_8 & z_8 & x_8y_8 & y_8z_8 & z_8x_8 \end{bmatrix}$$

where the triplet (x_i,y_i,z_i) is the input values of ith point. The product of VV' is a 6 x 6 symmetric matrix

$$VV' = \begin{bmatrix} \sum x_i^2 & \sum x_iy_i & \sum x_iz_i & \sum x_i^2y_i & \sum x_iy_iz_i & \sum x_i^2z_i \\ \sum x_iy_i & \sum y_i^2 & \sum y_iz_i & \sum x_iy_i^2 & \sum y_i^2z_i & \sum x_iy_iz_i \\ \sum x_iz_i & \sum y_iz_i & \sum z_i^2 & \sum x_iy_iz_i & \sum y_iz_i^2 & \sum x_iz_i^2 \\ \sum x_i^2y_i & \sum x_iy_i^2 & \sum x_iy_iz_i & \sum x_i^2y_i^2 & \sum x_iy_i^2z_i & \sum x_i^2y_iz_i \\ \sum x_iy_iz_i & \sum y_i^2z_i & \sum y_iz_i^2 & \sum x_iy_i^2z_i & \sum y_i^2z_i^2 & \sum x_iy_iz_i^2 \\ \sum x_i^2z_i & \sum x_iy_iz_i & \sum x_iz_i^2 & \sum x_i^2y_iz_i & \sum x_iy_iz_i^2 & \sum x_i^2z_i^2 \end{bmatrix}$$

where i varies from 1 to 8 and the summation adds all eight points. The product of V with vector P is

$$V \cdot P = \begin{bmatrix} x_1 & x_2 & x_3 & x_4 & x_5 & x_6 & x_7 & x_8 \\ y_1 & y_2 & y_3 & y_4 & y_5 & y_6 & y_7 & y_8 \\ z_1 & z_2 & z_3 & z_4 & z_5 & z_6 & z_7 & z_8 \\ x_1y_1 & x_2y_2 & x_3y_3 & x_4y_4 & x_5y_5 & x_6y_6 & x_7y_7 & x_8y_8 \\ y_1z_1 & y_2z_2 & y_3z_3 & y_4z_4 & y_5z_5 & y_6z_6 & y_7z_7 & y_8z_8 \\ z_1x_1 & z_2x_2 & z_3x_3 & z_4x_4 & z_5x_5 & z_6x_6 & z_7x_7 & z_8x_8 \end{bmatrix} \begin{bmatrix} p_1 \\ p_2 \\ p_3 \\ p_4 \\ p_5 \\ p_6 \\ p_7 \\ p_8 \end{bmatrix} = \begin{bmatrix} \sum x_ip_i \\ \sum y_ip_i \\ \sum z_ip_i \\ \sum x_iy_ip_i \\ \sum y_iz_ip_i \\ \sum x_iz_ip_i \end{bmatrix}$$

The most computation-intensive part is to invert the VV' matrix; the cost increases as the matrix size increases. A matrix is inevitable if and only if the determinant of the matrix is not zero:

$\det |VV'| \neq 0$

There are several ways to invert a matrix; we choose the Gaussian elimination for its less computational cost. The Gaussian elimination is the combination of the triangularization and back substitution. The triangularization will make all matrix elements in the lower left of the diagonal line zero. Consequently, the last row in the matrix contains only one element that is the solution for the last coefficient. This solution is substituted back into front rows to calculate other coefficients.

1.Triangularization

Let us rewrite the matrix into a set of simultaneous equations and substitute the matrix elements by k_{ij}:

$$k_{11} a_1 + k_{12} a_2 + k_{13} a_3 + k_{14} a_4 + k_{15} a_5 + k_{16} a_6 = q_1 \quad (1.1a)$$

$$k_{21} a_1 + k_{22} a_2 + K_{23} a_3 + k_{24} a_4 + k_{25} a_5 + k_{26} a_6 = q_2 \quad (1.1b)$$

$$k_{31} a_1 + k_{32} a_2 + k_{33} a_3 + k_{34} a_4 + k_{35} a_5 + k_{36} a_6 = q_3 \quad (1.1c)$$

$$k_{41} a_1 + k_{42} a_2 + k_{43} a_3 + k_{44} a_4 + k_{45} a_5 + k_{46} a_6 = q_4 \quad (1.1d)$$

$$k_{51} a_1 + k_{52} a_2 + k_{53} a_3 + k_{54} a_4 + k_{55} a_5 + k_{56} a_6 = q_5 \quad (1.1e)$$

$$k_{61} a_1 + k_{62} a_2 + k_{63} a_3 + k_{64} a_4 + k_{65} a_5 + k_{66} a_6 = q_6 \quad (1.1f)$$

where $k_{11}=\Sigma x_i^2$, $k_{12}=\Sigma x_i y_i$, $k_{13}=\Sigma x_i z_i$ $k_{14}=\Sigma x_i^2 y_i$ $k_{15}=\Sigma x_i y_i z_i$,$k_{16}=\Sigma x_i^2 z_i$ and $q_1=\Sigma x_i p_i$ Similar substitutions are performed for Eq. (1.1b) to Eq. (1.1f).

First iteration:

Eq. (1.1b) - (k_{21}/k_{11}) Eq (1.1a)

$$^1k_{22}\ a_2+{}^1k_{23},a_3+{}^1k_{24}\ a_4+{}^1k_{25}\ a_5+\ {}^1k_{26}\ a_6 = {}^1q_2 \qquad (1.1b1)$$

Eq. (1.1c) - (k_{31}/k_{11}) Eq. (1.1a)

$$^1k_{32}\ a_2+{}^1k_{33}\ a_3+{}^1k_{34}\ a_4+{}^1k_{35}\ a_<+\ {}^1k_{36}\ a_6 = {}^1q_3 \qquad (1.1c1)$$

Eq. (1.1d) - (k_{41}/k_{11}) Eq. (1.1a)

$$^1k_{42}\ a_2+{}^1k_{43}\ a_3+{}^1k_{44}\ a_4+{}^1k_{45}\ a_5+\ {}^1k_{46}\ a_6 = {}^1q_4 \qquad (1.1d1)$$

Eq. (1.1e) - (k_{51}/k_{11}) Eq. (1.1a)

$$^1k_{52}a_2+{}^1k_{53}a_3+{}^1k_{54}a_4+{}^1k_{55}a_5+{}^1k_{56}a_6 = {}^1q_5 \qquad (1.1e1)$$

Eq.(3.4f) - (k_{61}/k_{11}) Eq.(3.4a)

$$^1k_{62}a_2+{}^1k_{63}a_3+{}^1k_{64}a_4+{}^1k_{65}a_5+{}^1k_{66}a_6 = {}^1q_6 \qquad (1.1f1)$$

After the first iteration, the matrix elements k_{21}, k_{31}, k_{41}, k_{51}, and k_{61} are eliminated.

Second iteration:

Eq.(3.4c_1) - $({}^1k_{32}/{}^1k_{22})$ Eq.(3.4b_1)

$$^2k_{33}a_3+{}^2k_{34}a_4+{}^2k_{35}a_5+{}^2k_{36}a_6 = {}^2q_3 \qquad (1.1c2)$$

Eq.(3.4d_1) - $({}^1k_{42}/{}^1k_{22})$ Eq.(3.4b_1)

$$^2k_{43}a_3+{}^2k_{44}a_4+{}^2k_{45}a_5+{}^2k_{46}a_6 = {}^2q_4 \qquad (1.1d2)$$

Eq.(3.4e_1) - $({}^1k_{52}/{}^1k_{22})$ Eq.(3.4b_1)

$$^2k_{53}a_3+{}^2k_{54}a_4+{}^2k_{55}a_5+{}^2k_{56}a_6 = {}^2q_5 \qquad (1.1e2)$$

Eq.(3.4f_1) - $({}^1k_{62}/{}^1k_{22})$ Eq.(3.4b_1)

$$^2k_{63}a_3+{}^2k_{64}a_4+{}^2k_{65}a_5+{}^2k_{66}a_6 = {}^2q_6 \qquad (1.1e2)$$

After the second iteration, the elements ${}^1k_{32}$, ${}^1k_{42}$, ${}^1k_{52}$, and ${}^1k_{62}$, are eliminated.

Third iteration:

Eq.(3.4d_2) - $({}^2k_{43}/{}^2k_{33})$ Eq.(3.4c_2)

$$^3k_{44}a_4+{}^3k_{45}a_5+{}^3k_{46}a_6 = {}^3q_4 \qquad (1.1d3)$$

Eq.(3.4e_2) - $({}^2k_{53}/{}^2k_{33})$ Eq.(3.4c_2)

$$^3k_{54}a_4+{}^3k_{55}a_5+{}^3k_{56}a_6 = {}^3q_5 \qquad (1.1e3)$$

Eq.(3.4f$_2$) - ($^2k_{63}/^2k_{33}$) Eq.(3.4c$_2$)

$$^3k_{64}a_4+^3k_{65}a_5+^3k_{66}a_6 = ^3q_6 \qquad (1.1f3)$$

After the third iteration, the elements $^2k_{43}$, $^2k_{53}$, and $^2k_{63}$ are eliminated.
Fourth iteration:

Eq.(3.4e$_3$) - ($^3k_{54}/^3k_{44}$) Eq.(3.4d$_3$)

$$^4k_{55}a_5+^4k_{56}a_6 = ^4q_5 \qquad (1.1e4)$$

Eq.(3.4f$_3$) - ($^3k_{64}/^3k_{44}$) Eq.(3.4d$_3$)

$$^4k_{65}a_5+^4k_{66}a_6 = ^4q_6 \qquad (1.1f4)$$

After the fourth iteration, the elements $^3k_{54}$ and $^3k_{64}$ are eliminated.

Fifth iteration:

Eq.(3.4f$_4$) - ($^4k_{65}/^4k_{55}$) Eq.(3.4e$_4$)

$$^5k_{66}a_6 = ^5q_6 \qquad (1.1f5)$$

After the fifth iteration, the element 4k65 is eliminated. Now all the elements in the bottom-right triangle of the matrix are zero.

·2 Back Substitution

The ai value is obtained by back substituting ai+1 sequentially via Eqs. (1.1e4), (1.1d3), (1.1c2), (1.1b,), and (1.1a).

$$^5k_{66}a_6 = ^5q_6 \qquad (1.1f5)$$
$$^4k_{55}a_5+^4k_{56}a_6 = ^4q_5 \qquad (1.1e4)$$
$$^3k_{44}a_4+^3k_{45}a_5+^3k_{46}a_6 = ^3q_4 \qquad (1.1d3)$$
$$^2k_{33}a_3+^2k_{34}a_4+^2k_{35}a_5+^2k_{36}a_6 = ^2q_3 \qquad (1.1c2)$$
$$^1k_{22}\ a_2+^1k_{23},a_3+^1k_{24}\ a_4+^1k_{25}\ a_5+\ ^1k_{26}\ a_6 = ^1q_2 \qquad (1.1b1)$$
$$k_{11}a_1 + k_{12}\ a_2 + k_{13}\ a_3 + k_{14}\ a_4 + k_{15}\ a_5 + k_{16}\ a_6 = q_1 \qquad (1.1a)$$

From Eq. (1.1fs), we obtain

$$a_6 = ^5q_6/^5k_{66}$$

Substituting a6 into Eq. (1.1e4), we obtain

$$a_5 = [^4q_5-^4k_{56}(^5q_6/^5k_{66})]/^4k_{55}$$

We then substitute a_5 and a_6 into Eq. (1.1d3) to compute a_4. Continuing these back substitutions, we can determine all a_i.

APPENDIX C

Colorimetric values of the IT8

Sample Number	IT8.7			3x4			3x8			3x11			3x20		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
A1	3.48	2.96	1.99	2.19	2.39	5.05	1.27	1.29	2.58	1.25	1.2	2.43	1.21	1.1	1.94
A2	4.31	2.9	1.62	2.46	2.26	4.67	1.7	1.48	2.76	1.56	1.22	2.44	1.07	0.69	0.87
A3	6.24	3.7	1.7	3.54	2.62	4.75	3.22	2.28	3.58	1.86	1.08	1.82	2.31	1.32	1.97
A4	6.81	4	1.78	3.88	2.82	4.84	3.84	2.57	3.63	2.32	1.31	2.32	2.77	1.56	2.22
A5	13.11	11.65	7.96	11.09	11.96	11.92	13.58	14.37	12.6	11.85	11.12	11.21	11.65	9.5	8.77
A6	14.46	10.82	6.35	10.6	9.1	10.02	14.25	12.45	10.84	12.4	8.02	8.31	10.66	5.6	4.15
A7	17.38	11.22	5.61	12.57	8.3	8.33	16.11	10.96	9.53	12.53	6.34	4.22	13.28	6.72	3.8
A8	19.06	10.95	4.92	11.21	5.7	4.17	15.96	8.82	6.66	14.6	7.3	4.52	15.73	7.86	4.04
A9	42.63	42.38	32.93	40.52	42.14	36.37	44.26	45.03	36.05	41.7	40.2	32.1	42.3	41.59	33.09
A10	44.37	41.96	32.1	42.28	41.47	35.68	45.92	44.42	35.78	43.02	39.53	30.36	43.66	40.91	31.74
A11	47.16	42.41	30.92	45.31	41.49	34.77	49.3	44.88	35.5	45.76	39.86	29.37	46.9	41.93	31.58
A12	48.98	42.03	28.95	47.22	40.69	31.68	51.34	44.22	33.25	47.96	40.15	27.44	49.1	42.18	29.67
A13	72.42	75.52	64.39	80.06	83.13	68.01	72.11	75.35	64.43	71.82	73.61	63.3	71.4	75.23	65.16
A14	74.25	76.56	64.53	80.24	83.24	67.53	74.23	76.81	65.05	74.04	75.45	63.7	73.37	75.87	64.3
A15	74.25	76.74	63.45	79.97	83.06	66.4	74.13	76.98	64.4	73.86	75.35	62.94	73.48	76.28	63.93
A16	71.78	74.79	62.87	79.87	82.98	67.11	71.71	74.69	63.38	71.02	72.39	61.78	69.79	73.37	63.74
A17	74.06	76.43	63.25	80.01	83.05	66.54	73.96	76.57	64.26	73.91	75.35	63.02	73.04	75.6	63.52
A18	71.98	75.13	62.93	79.56	82.77	66.09	71.84	75.13	63.6	71.28	72.94	62.03	70.48	74.17	64.1
A19	71.74	74.67	63.69	78.74	82.15	67.12	71.37	74.13	63.42	70.4	71.93	62.42	69.6	73.17	63.83
A20	1.5	1.19	0.79	1.21	1.3	2.93	0.64	0.64	0.74	0.59	0.58	0.69	0.57	0.55	0.62
A21	5.62	3.37	0.86	2.9	2.25	3.97	2.3	1.73	2.4	1.41	0.87	1.11	1.63	0.98	1.08
A22	10.24	5.63	0.93	6.63	4.15	4.19	6.82	3.87	2.78	5.4	2.9	2.71	6.22	3.35	2.26
B1	3.2	2.91	1.63	2.07	2.3	4.58	0.99	1.04	1.69	1.01	1.04	1.68	0.98	0.96	1.3
B2	3.93	2.98	1.1	2.09	2.13	4.12	1.23	1.14	1.59	1.21	1.05	1.6	1.22	1.03	1.23
B3	5.14	3.4	0.9	2.64	2.3	4	2.02	1.66	2.3	1.74	1.27	1.96	1.31	0.81	0.74
B4	5.86	3.69	0.9	3.13	2.49	4.21	2.44	1.86	2.55	1.41	0.86	1.1	1.74	1.06	1.08
B5	12.75	11.28	5.69	10.2	10.94	9.72	13.12	13.64	9.73	11.4	10.53	8.65	10.93	8.93	6.45
B6	14.41	11.08	3.62	10.58	9.39	7.77	13.76	11.93	7.42	11.96	8.25	6.17	11.96	7.28	3.56
B7	17.71	11.69	2.32	12.78	8.56	6.45	16.17	10.82	6.12	12.62	6.48	2.94	13.64	7.05	2.08
B8	19.2	11.64	1.67	12.55	7.08	4.73	16.56	9.4	4.69	14.81	7.51	3.2	15.95	8.14	2.19
B9	42.33	42.39	30.36	39.56	41.62	32.52	43.96	45	33.68	41.94	40.98	29.63	42.68	42.45	31.11

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B10	43.7	41.86	27.22	40.92	40.84	30.21	45.68	44.54	31.21	42.93	40.18	25.77	44.03	42.15	27.62
B11	46.19	42.29	24.19	43.62	41.01	27.13	49.18	45.44	28.95	45.94	41.36	22.92	46.3	42.78	25.19
B12	48.1	42.37	22.3	45.74	40.86	25.89	51.81	45.73	28.38	48.67	42.52	20.98	49.03	43.83	23.65
B13	64.76	69.95	62.85	67.04	73.81	65.42	63.21	68.43	59.69	63.46	66.5	59.5	62.13	68.06	63.07
B14	70.97	71.01	61.94	77.15	76.85	64.66	69.36	68.79	61.14	68.73	67.73	59.45	68.43	68.03	60.14
B15	72.35	75.02	54.61	77.59	80.64	56.63	71.73	75.03	55.7	70.54	71.78	53.41	70.16	73.06	54.17
B16	59.77	62.96	52.63	59.98	64.33	53.97	57.57	60.76	50.42	56.86	57.84	48.4	55.84	58.95	51.08
B17	68.77	69.07	52.46	74.11	73.19	54.54	67.51	67.56	52.63	66.04	64.9	49.07	65.01	64.79	50.06
B18	61.89	67.43	52.24	62.51	69.75	53.6	59.92	65.98	48.94	60.03	63.2	49.74	59.04	65.29	53.35
B19	61	63.87	59.87	62.55	66.61	62.44	58.74	61.23	56.88	57.8	58.68	55.35	57.01	59.59	57.88
B20	3.21	2.18	0.85	1.61	1.57	3.42	0.89	0.83	1.12	0.84	0.74	1.1	0.79	0.63	0.7
B21	9.49	5.34	0.92	5.99	3.82	4.09	6.82	4.02	3.09	4.52	2.47	2.48	5.21	2.84	2.14
B22	30.89	27.26	14.09	26.87	26.05	17.18	33.43	31.48	19.06	31.19	27.81	16	32.17	28.75	15.6
C1	4.31	4.28	2.13	2.38	2.83	4.7	1.57	1.75	2.66	1.46	1.66	2.58	1.3	1.4	1.44
C2	4.92	4.63	1.48	2.49	2.91	4.17	1.57	1.64	1.69	1.64	1.72	1.89	1.11	1.04	0.44
C3	6.15	5.62	1.17	3.02	3.33	3.8	1.47	1.43	0.53	1.84	1.82	1.08	1.64	1.42	0.54
C4	6.59	6	1.18	3.17	3.49	3.76	1.86	1.79	0.65	1.88	1.76	0.74	1.88	1.63	0.59
C5	25.41	25	11.15	21.51	23.87	12.83	27.15	28.57	12.96	26.44	26.89	12.13	26.81	26.98	11.02
C6	26.55	24.1	5.34	19.58	18.73	2.29	27.44	25.19	2.62	26.09	23.4	2.43	27.23	24.62	2.45
C7	31.23	27.07	2.8	24.73	21.87	2.39	32.98	28.34	2.66	31.79	27.34	2.66	32.68	29.01	2.7
C8	33.73	28.56	2.05	27.04	23.13	2.36	35.59	29.68	2.66	34.8	29.26	2.64	35.18	30.91	2.7
C9	48.78	49.95	33.58	46.52	49.18	34.97	49.49	51.25	35.11	47.44	47.18	32.21	47.84	48.97	33.99
C10	50.22	50.17	27.11	47.71	48.67	28.07	51.82	52.27	29.05	49.21	48.08	24.44	49.78	50.21	28.69
C11	52.03	50.29	22.36	49.16	48	22.36	54.07	52.25	24.25	51.38	49.12	18.36	51.66	50.67	23.76
C12	54	50.89	18.24	51.24	48	15.42	57.68	53.73	20.23	53.56	49.67	8.47	53.69	51.72	19.25
C13	55.75	63	60.52	54.75	64.45	62.72	54.07	61.1	55.65	54.33	59.54	56.92	53.41	60.37	60.68
C14	64.33	60.45	57.1	69.59	64.04	60.06	61.67	56.96	55.86	61.05	56.08	53.97	61.24	57.19	54.67
C15	69.93	72.59	44.15	73.43	75.57	42.77	68.21	71.78	44.19	67.44	68.53	41.45	68.28	71.04	42.6
C16	45.03	47.02	38.7	42.73	46.42	40.46	45.43	48.34	38.87	43.39	44.12	35.26	43.73	45.14	36.61
C17	60.08	56.76	39.78	62.95	58.56	43.94	60.52	56.76	42.99	57.25	52.85	35.47	56.99	53.51	38.3
C18	51.29	58.85	41.57	47.67	56.82	39.4	49.67	57.76	37.53	50.52	56.44	39.26	50.29	58.16	45.46
C19	47.74	49.06	53.2	47.45	50.19	55.97	47.01	48.93	52.77	45.47	45.15	49.88	45.42	45.9	50.67
C20	2.14	1.72	0.79	1.34	1.47	3.08	0.63	0.62	0.74	0.64	0.62	0.75	0.65	0.62	0.61

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C21	23.65	18.3	5.51	18.67	15.99	9.77	24.63	20.93	10.24	22.22	16.62	8.36	23.22	17.38	5.74
C22	36.2	34.14	20.1	32.65	33.09	22.85	38.81	38.18	24.7	36.32	34.04	20.16	37.18	35.3	20.98
D1	4.1	4.35	2.18	2.26	2.82	4.44	1.31	1.53	2.26	1.34	1.62	2.31	1.14	1.33	1.1
D2	4.22	4.7	1.46	1.97	2.6	3.49	0.81	0.86	0.4	0.83	0.95	0.45	0.89	0.99	0.44
D3	4.48	5.06	1.22	1.98	2.67	3.09	0.84	0.88	0.38	0.98	1.16	0.52	1.04	1.19	0.54
D4	5.36	6.31	1.3	2.09	3.01	2.28	1.16	1.36	0.51	1.3	1.74	0.67	1.36	1.73	0.65
D5	27.42	29.26	13.68	22.98	27.3	13.35	28.77	32.28	13.14	28.76	31.5	13.83	29.28	31.84	14.56
D6	26.18	28.35	7.46	19.58	22.39	2.72	26.43	28.02	2.88	26.44	28.31	2.95	26.56	28.67	2.94
D7	27.44	30.16	4.02	21.06	23.84	2.8	28.66	30.08	3	29.13	31.29	3.16	28.37	31.26	3.15
D8	30.12	33.58	2.53	23.94	26.88	2.93	31.71	33.28	3.13	32.75	35.35	3.38	31.24	35.04	3.36
D9	55.6	59.17	39.49	54.08	58.53	39.61	54.4	58.53	37.71	54.23	55.67	37.25	53.72	57.52	40.19
D10	55.65	59.28	31.67	52.67	56.94	29.65	54.77	59	30.11	55.11	57.14	30.98	55.47	59.68	35.81
D11	56.81	60.21	25.81	53.07	56.44	19.68	55.27	59.05	22.06	56.95	59.17	26.42	57.33	61.92	31.72
D12	56.56	60.1	21.6	48.07	48.55	3.82	53.38	56.58	11.88	57.36	60.14	22.46	58.02	63.24	29.11
D13	47.95	56.88	59.08	45.44	56.3	61.14	46.71	55.16	54.03	47.86	55.6	55.79	46.46	54.4	59.28
D14	59.24	52.32	53.4	62.92	54.24	55.76	56.53	48.86	51.28	56.54	48.76	51.32	57.62	50.72	52.12
D15	69.08	71.56	36.23	71.06	72.62	32.77	67.95	71.56	37.72	67.57	69.09	36.59	68.37	70.74	36.84
D16	33.97	35.52	29.06	30.85	34.64	30.23	35.87	38.9	31.88	34.7	35.74	29.43	35.16	36.02	29.94
D17	53.91	48.13	31.15	53.73	47.65	34.18	56.19	49.88	35.03	53.28	46.55	28.79	53.1	47.35	31.12
D18	41.63	50.73	33.43	36.27	46.28	30.32	40.8	50	28.55	43.7	52.05	35.49	43.36	52.34	40.86
D19	36.97	37.58	47.64	36.12	38.43	50.73	37.86	39.94	50.91	36.62	36.47	47.85	36.68	36.31	47.04
D20	15.39	11.77	3.23	11.05	9.54	7.08	15.08	12.78	6.92	12.94	8.94	5.72	13.17	8.19	2.88
D21	23.89	23.78	14.58	20.58	23.35	16.94	25.93	28.11	18.76	24.89	25.73	16.89	25.4	25.55	16.17
D22	40.41	39.93	23.79	36.95	38.49	25.26	42.49	43.17	26.08	40.6	39.53	22.6	41.5	41.13	24.58
E1	3.79	4.4	2.19	2.19	2.87	4.55	1.22	1.49	1.98	1.24	1.67	2.13	0.85	1	0.48
E2	3.7	4.94	1.54	1.87	2.81	3.15	0.76	0.89	0.42	0.82	1.17	0.53	0.91	1.34	0.6
E3	4.1	5.92	1.36	1.43	2.38	1.47	0.82	1.08	0.45	1.11	1.94	0.8	1.17	2.08	0.84
E4	4.71	7.08	1.48	1.31	2.24	0.92	1.13	1.76	0.69	1.56	3.12	1.23	1.68	3.34	1.28
E5	13.4	15.89	7.86	10.99	15.25	9.18	13.78	17.91	8.47	13.82	18.36	9.12	13.89	17.7	6.34
E6	11.5	15.02	4.52	5.33	8.36	1.99	8.46	11.14	2.08	9.54	13.63	2.37	9.53	13.32	2.31
E7	10.32	15.03	2.74	4.55	7.89	2.08	7.25	10.46	2.04	9.1	14.13	2.54	8.92	13.8	2.42
E8	11.47	17.87	2.35	5.57	9.95	2.21	9.52	13.87	2.39	11.8	18.44	2.85	11.01	17.32	2.74
E9	38.39	42.12	27.65	34.74	40.19	29.09	39.96	44.56	29.11	39.39	42.47	28.66	39.56	43.08	30.85

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E10	37.64	42.72	23.84	33.03	39.64	22.42	38.53	44.22	22.04	39.59	44.34	25	39.83	45.07	28.75
E11	36.48	42.98	20.61	30.24	37.99	14.78	36.06	42.71	13.06	39.41	45.93	23.4	39.52	46.41	28.3
E12	35.16	42.67	17.3	26.3	32.19	3.52	32.43	37.29	3.68	38.44	46.29	20.89	38.56	46.97	28.17
E13	39.64	49.5	55.57	35.48	46.22	56.37	38.57	48.05	51.59	39.6	49.32	52.82	38.98	47.88	55.28
E14	54.09	45.33	48.97	55.02	45.35	49.63	51.03	42.18	46.9	51.33	41.84	47.52	52.96	44.64	48.75
E15	66.63	68.59	27.3	66.42	66.18	18.28	65.24	67.76	26.28	65.31	66.81	27.14	66.36	68.43	29.62
E16	24.94	26.44	21.17	21.84	25.88	22.94	27.28	30.92	25.72	26.03	28.48	23.23	26.71	28.32	22.75
E17	47.48	40.27	22.22	44.73	38.26	26.05	51.43	43.28	28.71	48.17	40.34	22.36	48.98	42.11	24.72
E18	33	42.59	24.8	26.78	36.85	19.27	32.21	41.64	18.07	36.15	46.16	28.26	36.3	46.13	34.29
E19	28.37	28.67	41.75	27.57	30.02	43.53	30.23	32.97	47.46	29.49	30.1	44.16	29.3	29.21	43.28
E20	29.61	22.53	1.72	20.51	15.07	1.86	30.75	23.34	2.24	28.33	20.82	2.16	31.08	24.21	2.31
E21	20.14	17.3	3.43	15.91	15.58	5.33	18.66	16.3	2.02	16.99	13.76	1.82	17.82	14.2	1.79
E22	32.15	28.91	9.94	27.5	26.84	11.39	34.5	32.42	11.71	32.68	29.83	8.88	33.26	30.83	8.07
F1	1.58	2.01	1.32	1.39	1.71	3.37	0.61	0.65	0.82	0.68	0.77	0.88	0.64	0.73	0.68
F2	1.36	2.27	1.19	1.23	1.59	2.74	0.55	0.62	0.59	0.57	0.7	0.56	0.58	0.67	0.39
F3	1.21	2.41	1.15	1.16	1.6	2.55	0.54	0.6	0.48	0.55	0.64	0.37	0.58	0.72	0.4
F4	1.54	3.27	1.32	1.15	1.76	2.35	0.54	0.61	0.36	0.59	0.82	0.43	0.61	0.99	0.48
F5	6.54	8.6	5.5	4.61	7.03	7.83	5.11	7.6	7.23	5.29	8.45	7.38	4.94	7.94	5.01
F6	5.69	8.99	4.84	3.83	6.9	6.23	3.56	6.41	4.51	4.04	8.07	4.51	2.52	5.52	1.74
F7	4.86	9.22	4.12	2.42	5.46	3.25	1.5	3.27	1.28	2.13	5.31	1.88	2.29	5.75	1.91
F8	3.87	9.01	3.52	1.3	3.1	1.32	1.24	2.9	1.19	1.92	5.29	1.93	2.09	5.81	2.07
F9	37.78	41.72	31.3	34.75	40.35	32.85	39.35	44.06	33.29	38.53	41.8	32	38.77	42.31	32.79
F10	36.47	42.23	31.49	32.47	39.69	32.4	37.6	44.14	31.94	37.74	42.97	32.44	37.97	43.35	33.9
F11	34.8	42.11	30.3	30.05	38.65	29.79	35.53	43.38	29.06	36.69	44.02	32.36	36.95	44.02	34.84
F12	32.71	41.71	28.97	27.24	37.01	27.14	32.79	41.89	26.26	35.26	44.55	31.62	35.24	44.18	35.61
F13	34.18	44.33	52.54	29.28	39.74	51.64	33.8	43.54	50.52	34.13	44.7	50.61	34.12	43.86	51.61
F14	49.04	38.94	44.39	47.18	37.3	43.28	46.16	36.67	42.49	46.31	35.52	43.39	48.1	38.26	44.77
F15	64.89	66.33	22.09	61.77	57.39	4.15	63	64.22	17.48	63.71	64.95	20.59	64.63	66.5	25.85
F16	18.94	20.15	15.79	16.2	19.9	17.95	20.69	24.35	19.69	20.13	22.81	18.51	20.57	22.47	17.33
F17	42.47	34.34	16.91	37.91	31.33	20.73	46.43	37.78	23.52	43.31	34.96	18.58	44.76	37.25	19.67
F18	26.91	36.53	19.37	20.23	29.93	12.23	25.81	34.69	9.7	29.91	40.69	22.37	29.93	40.2	27.61
F19	22.23	22.12	36.89	21.3	23.69	36.65	24.66	27.68	44.15	24.17	24.93	41.18	24	23.96	40.67
F20	28.05	27.78	14.06	24.2	26.59	15.94	30.38	31.84	16.85	29.37	29.76	15.3	30.04	30.21	14.94

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F21	35.68	33.65	12.4	30.9	31.4	12.51	38.02	37	13.15	36.12	34.38	9.94	37.14	36.1	11.94
F22	38.98	37.94	17.93	34.74	35.86	19.16	41.33	41.22	20.52	39.58	38.26	16.66	40.3	39.7	19.59
G1	2.32	2.93	2.43	1.9	2.43	4.97	0.98	1.13	2.27	0.94	1.18	2.11	0.96	1.22	1.68
G2	2.01	3.15	2.7	1.75	2.42	4.91	0.95	1.22	2.29	0.95	1.4	2.24	0.93	1.46	1.86
G3	1.65	3.27	3.05	1.69	2.45	4.86	0.92	1.26	2.47	1.08	1.78	2.92	1.08	1.96	2.52
G4	1.97	4.07	3.75	1.89	3.02	5.48	1.27	1.91	3.92	1.54	2.85	4.57	1.43	3.05	3.62
G5	8.98	11.46	9.25	7.72	11.44	11.97	9.57	13.69	12.95	9.37	13.93	12.43	9.49	13.68	10.65
G6	7.86	11.74	10.04	6.5	10.83	11.74	8.06	12.92	13.05	8.16	14.09	12.55	8.42	14.19	11.1
G7	6.62	11.55	10.5	5.33	9.82	11.7	6.52	11.66	13.07	6.45	12.77	12.33	6.63	13.16	10.62
G8	4.79	10.26	10.68	4.18	8.43	11.69	4.71	9.41	13.01	4.64	10.51	12.36	4.67	11.04	10.85
G9	36.76	40.85	32.32	33.49	39.36	33.77	38.16	43.36	33.98	37.29	40.87	31.94	37.76	41.39	33.01
G10	34.83	40.86	34.74	31.05	38.64	35.9	36.3	43.03	36.29	36.06	41.81	34.66	35.89	41.54	35.27
G11	33.94	41.9	36.83	29.49	38.59	36.97	34.84	43.33	36.98	35.52	43.52	37.84	35.14	42.73	39.36
G12	32.34	41.8	37.42	27.08	37.32	36.35	32.83	42.43	36.81	34.06	43.89	38.42	33.55	42.76	40.06
G13	28.28	38.67	49.59	23.07	33.22	47.05	28.2	38.17	48.7	28.07	39.7	48.33	28.71	39.4	48.38
G14	43.85	32.52	39.8	40.07	29.97	36.84	40.82	30.92	37.88	41.01	28.95	39.14	42.11	30.91	40.38
G15	63.19	63.77	15.86	60.48	55.33	4.03	60.28	57.07	4.06	60.81	57.92	4.09	62.67	64.32	19.91
G16	12.89	13.78	10.72	11.56	14.63	13.88	14.19	17.37	15.2	13.66	16.32	14.35	13.85	15.78	12.58
G17	36.46	27.46	11.33	30.24	23.33	15.32	39.26	30.36	17.53	36.37	27.09	14.23	38.62	30.12	14.48
G18	20.71	30.14	14.11	13.96	21.18	2.92	19.43	26.22	3.1	23.41	34.5	15.24	23.3	33.95	20.26
G19	16.33	15.8	31.57	16.6	18.6	31.28	19.05	22.09	39.02	18.86	19.79	36.92	18.46	18.49	36.58
G20	37.79	37.76	17.02	33.41	35.6	16.98	40.33	41.26	18.06	38.92	38.95	15.92	39.28	40.05	18.81
G21	36.68	36.63	10.97	29.35	29.88	2.96	36.85	35.91	3.2	36.13	34.95	3.18	38.09	39.43	10.61
G22	47.46	46.45	3.53	40.85	38.49	3.33	50.34	45.97	3.7	50.18	47.44	3.69	46.17	46.3	3.77
H1	2.48	2.9	2.99	2.17	2.66	5.96	1.27	1.44	3.68	1.19	1.4	3.31	1.12	1.34	2.85
H2	2.17	2.88	3.91	2.24	2.89	6.72	1.56	1.86	5.35	1.41	1.8	4.67	1.43	1.83	4.5
H3	1.82	2.76	4.97	2.55	3.33	7.78	1.81	2.26	6.87	1.74	2.26	6.57	1.83	2.53	6.81
H4	2.33	3.73	7.46	3.12	4.3	9.83	2.67	3.87	10.2	2.61	3.98	9.87	2.77	4.39	10.34
H5	9.48	11.41	11.33	8.69	12.19	14.01	10.48	14.46	15.73	9.96	13.8	14.85	10.56	14.01	13.96
H6	8.23	11.05	13.93	7.64	11.51	15.93	9.12	13.62	18.25	8.8	13.56	17.17	9.01	13.77	16.63
H7	7.53	11	17.89	7.14	11.15	18.61	8.26	13.24	21.37	7.87	13.08	20.36	8.09	13.39	20.7
H8	7.26	11.1	21.97	6.95	10.95	20.49	8.44	13.48	26.32	7.58	12.98	23.6	7.51	13.2	23.58
H9	36.95	40.74	36.55	34.16	39.65	38.44	38.04	42.98	38.23	36.99	40.2	35.46	37.18	40.34	35.82

H10	36.31	41.1	40.56	33.41	39.85	42.72	37.62	43.33	42.58	36.33	40.72	40.04	36.46	40.67	40.49
H11	35.21	41.2	46.08	32.37	39.74	47.83	35.79	42.61	47.74	35.3	41.19	46.24	35.38	40.79	46.11
H12	34.43	41.26	49.4	31.36	39.34	50.63	34.64	42	49.6	34.25	41.36	47.96	34.42	40.9	48.14
H13	22.19	32.28	45.33	17.33	26.58	41.44	22.56	32.26	46.48	21.34	32.87	44.07	22.55	33.74	44.31
H14	37.1	24.98	33.51	29.59	19.39	26.13	33.83	24.08	31.71	31.62	18.37	26.79	31.32	18.18	26.63
H15	60.71	60.4	11.21	57.18	51.97	3.86	61.05	56.46	4.03	59.83	56.66	4.09	59.37	60.7	14.83
H16	7.58	8.08	6.38	6.11	7.75	9.78	6.89	8.63	10.02	6.58	8	9.57	6.14	7	7.88
H17	31.06	21.71	7.38	23.07	15.46	10.43	31.39	22.49	13.04	28.4	17.76	9.88	30.63	20.9	9.51
H18	14.67	23.46	9.74	8.03	14.1	2.6	13.21	19.69	2.75	15.77	25.65	7.61	15.86	25.94	10.47
H19	10.59	9.62	25.14	11.8	13.17	24.85	13.04	15.95	31.56	13.04	13.83	29.14	12.15	12	29.36
H20	41.43	43.29	17.14	35.72	39.28	12.41	41.85	44.31	12.33	42.25	43.91	14.73	43.53	46.43	22.04
H21	32.58	34.56	22.78	28.54	32.91	23.87	34.62	37.96	25.86	33.71	35.78	23.33	34.24	36.15	24.78
H22	35.99	40.14	12.22	28.09	31.74	3.3	35.32	37.66	3.58	37.5	41.74	8.7	39.13	44.42	19.46
I1	3.79	3.94	4.9	3.34	4.07	7.96	2.72	3.22	7.49	2.56	2.99	7.15	2.48	2.72	6.55
I2	3.92	4.02	7.65	4.05	4.87	10.17	3.65	4.39	10.78	3.38	3.86	9.85	3.34	3.62	9.69
I3	3.89	3.9	10.59	4.68	5.62	12.44	4.35	5.47	14.32	3.83	4.22	12.44	3.83	4.05	12.8
I4	4.08	3.95	14.53	5.22	6.04	14.98	5.07	6.75	17.84	4.55	5.17	15.61	4.49	4.87	16.72
I5	14.24	15.19	15.11	13.06	16.43	17.65	16.02	19.59	20.27	15.24	17.89	18.83	15.43	17.25	17.24
I6	13.83	14.73	18.69	13.09	16.27	20.58	15.65	19.49	23.51	14.77	17.49	21.6	15.15	17.09	21.12
I7	13.71	14.5	23.32	13.26	16.43	23.22	15.98	19.86	29.14	15.21	17.85	26.79	15.52	17.43	26.49
I8	14.07	14.68	27.86	14.01	16.99	27.67	16.37	20.46	34.05	16.07	18.57	32.03	15.95	17.83	31.75
I9	38.34	40.31	35.86	35.66	39.6	38.2	39.69	42.82	38.21	38.12	39.14	34.78	38.62	39.97	35.6
I10	39.09	40.95	40.71	37.2	40.76	44.21	40.17	43.11	43.91	38.42	39.11	40.21	38.75	39.73	39.84
I11	39.61	41.16	44.75	37.96	41.44	47.29	40.23	42.85	46.46	38.8	39.24	43.47	39.1	39.71	43.72
I12	39.25	40.64	48.56	38.42	41.51	52.03	39.91	42.32	51.12	38.73	39.01	48.32	38.72	39.25	47.13
I13	17.28	26.78	40.57	12.92	21.12	35.32	17.43	26.75	41.24	16.07	26.79	39.03	17.22	28.24	38.75
I14	31.9	19.78	28.42	22.76	12.75	17.46	28.15	18.68	25.21	21.41	10.18	9.86	21.38	10.13	10.06
I15	58.98	57.87	7.98	55.65	49.99	3.8	60.42	54.98	3.92	60.55	56.73	4.09	57.15	57.62	10
I16	4.53	4.85	3.81	3.05	3.78	6.7	2.44	2.96	5.52	2.38	2.95	5.42	2	2.37	4.11
I17	26.4	17.11	4.44	18.34	10.69	7.25	25.01	15.52	8.95	19.99	9.97	3.92	21.94	11.46	4.07
I18	10.89	18.87	6.61	4.8	9.78	2.3	8.27	13.74	2.41	10.28	17.76	2.89	9.51	16.8	2.79
I19	7.25	6.17	20.66	8.25	9.15	19.33	9.44	11.85	26.64	8.91	9.26	23.56	7.81	7.28	23.04
I20	41.81	46.72	17.38	33.18	36.78	3.53	39.19	41.76	3.65	44.22	48.79	18.4	44.67	50.6	26.45

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I21	11.84	16.58	3.85	5.78	9.4	2.09	9.25	12.92	2.17	11	16.1	2.6	10.9	15.87	2.53
I22	27.8	36.02	17.91	21.64	30.41	11.4	27.13	34.76	8.2	30.88	40.1	20.48	30.94	39.9	25.04
J1	1.97	1.75	2.57	1.99	2.2	5.64	1.08	1.09	3.03	1	0.98	2.7	0.98	0.94	2.59
J2	2.23	1.72	4.32	2.51	2.71	7.2	1.88	1.92	6.53	1.75	1.63	6.09	1.8	1.54	6.17
J3	2.67	1.79	7.18	3.16	3.2	9.03	2.81	2.93	9.72	2.45	2.11	8.51	2.56	2	8.73
J4	2.83	1.66	9.73	3.55	3.4	10.53	3.41	3.52	12.44	2.9	2.33	10.18	2.77	1.92	9.72
J5	11.47	11.56	11.79	10.51	12.83	14.84	12.96	15.58	17.01	11.78	13.32	15.64	11.89	12.55	14.22
J6	11.75	11	15.02	10.98	12.52	17.46	13.44	15.81	20.54	12.13	12.57	17.89	11.58	10.75	16.39
J7	12.06	10.49	19.15	11.89	12.77	19.66	14.59	16.48	25.62	12.43	11.7	21.35	11.25	9.1	18.96
J8	12.67	10.5	21.95	12.4	12.66	21.6	15.37	16.96	28.94	13.02	11.55	23.61	11.59	8.52	20.21
J9	39.43	40.54	37.22	37.48	40.35	40.13	40.83	43.05	40.62	38.79	38.83	36.21	39.04	39.48	36.43
J10	40.66	40.94	39.26	39.21	41.09	42.94	41.58	42.9	42.8	39.56	38.56	38.5	40.21	39.6	38.8
J11	42.15	41.07	45.09	41.58	41.91	48.78	42.7	42.55	47.59	40.49	37.97	43.45	40.79	39.03	42.9
J12	41.82	40.12	47.36	41.11	40.97	50.65	42.25	41.8	50.29	40.52	37.29	46.44	41.18	38.48	46.49
J13	13.63	22.28	37.06	10.46	17.45	31.87	13.8	21.99	38.56	12.27	21.46	35.32	12.88	22.77	34.55
J14	27.85	16.1	24.48	17.05	8.38	9.4	23.79	14.54	20.46	19.64	9.38	9.53	19.63	9.35	9.8
J15	57.37	55.64	5.97	54	48.07	3.71	59.55	53.55	3.88	60.07	56.09	4.11	53.9	52.27	4.01
J16	2.78	2.96	2.32	1.97	2.45	4.96	1.02	1.16	2.41	1.02	1.17	2.3	0.93	1.06	1.68
J17	22.74	13.79	2.7	13.63	7.07	4.12	19.68	10.91	5.79	17.53	8.79	3.69	18.58	9.37	2.82
J18	8.54	15.72	4.59	3.28	7.36	2.05	5.18	9.61	2.12	6.83	13.22	2.63	6.36	12.72	2.57
J19	5.15	3.95	16.98	6.09	6.38	15.77	6.54	8	21.29	5.96	5.79	18.09	5.29	4.38	18.14
J20	30.11	38.95	24.57	24.56	34.24	21.22	30.23	39.32	20.82	32.78	42.22	27.41	33.06	42.07	31.46
J21	5.68	11.08	2.12	1.9	4.5	1.65	2.36	5.03	1.58	3.4	7.9	2.19	3.34	7.89	2.13
J22	1.27	2.51	1.12	1.12	1.55	2.35	0.54	0.59	0.42	0.56	0.66	0.39	0.58	0.73	0.4
K1	4.61	3.94	4.38	3.42	3.58	7.43	2.9	3	6.89	2.59	2.33	6.14	2.56	2.02	5.37
K2	5.93	4.05	6.51	4.48	3.96	8.62	4.5	4.04	9.31	3.87	2.48	6.67	2.55	1.32	4.29
K3	7.37	4.13	8.9	5.65	4.07	9.38	6.24	4.95	11.6	3.94	1.97	5.43	4.34	2.15	5.56
K4	9.21	4.76	12.45	7.26	4.76	10.78	8.48	6.62	14.18	5.77	2.82	6.42	6.34	3.06	7.02
K5	15.84	14.91	14.37	13.97	15.72	17.17	17.51	19.36	19.89	15.99	16.18	17.54	15.68	14.62	15.54
K6	17.06	14.06	17.18	15.04	14.74	18.92	18.35	18.56	22.02	15.96	12.92	17.74	15.03	10.18	14.59
K7	18.61	13.42	20.45	15.41	12.92	18.88	19.58	17.95	25.13	15.66	9.61	17.12	12.1	5.85	7.81
K8	21.05	13.66	24.66	16.75	11.6	20.05	21.29	17.56	27.37	14.62	7.14	11.09	13.97	6.64	9.3
K9	41.46	41.06	36.87	39.5	40.63	40.27	42.7	43.37	40.4	40.44	38.65	35.72	40.55	39.35	36.16

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K10	42.51	40.07	39.13	41.22	40.29	42.51	43.4	41.97	42.84	40.57	36.7	37.42	41.59	38.3	38.12
K11	45.23	40.62	43.98	44.39	40.88	47.1	44.77	41.13	45.65	42.55	36.47	42.02	43.91	38.78	42.96
K12	47.03	40.75	45.34	46.26	40.7	47.36	45.54	40.11	46.49	44.04	36.52	43.16	45.54	38.75	44.81
K13	11	18.78	33.39	8.7	14.72	28.76	11.4	18.68	35.37	9.92	17.83	32.48	10.02	18.57	31.31
K14	22.56	11.79	19.29	13.39	6.53	7.16	18.8	10.61	15.73	16.77	8.06	8.85	17.69	8.46	9.31
K15	53.45	50.19	2.92	48.69	42.81	3.46	57.54	50.24	3.7	58.04	52.71	3.81	51.24	49.2	3.77
K16	1.23	1.27	1.03	1.23	1.39	3.19	0.55	0.55	0.7	0.56	0.58	0.72	0.6	0.62	0.63
K17	18.58	10.4	1.38	10.74	5.52	3.19	14.12	7.17	2.8	14.83	7.5	3.47	15.94	8.1	2.66
K18	4.59	9.92	2.16	1.53	3.63	1.42	1.5	3.47	1.3	2.45	6.41	2.05	2.51	6.63	2.08
K19	3.14	1.97	12.49	4.17	3.97	12.38	3.94	4.45	14.71	3.51	3	12.39	3.48	2.63	13.02
K20	2.47	3.32	2.02	1.5	2.03	3.78	0.78	0.95	1.35	0.78	1.07	1.34	0.69	0.93	0.62
K21	1.31	1.83	1.57	1.33	1.61	3.58	0.68	0.73	1.05	0.63	0.73	0.96	0.63	0.73	0.81
K22	1.55	2.06	2.98	1.83	2.28	5.55	1.06	1.16	3.33	0.97	1.13	2.78	1	1.19	2.73
L1	3.24	2.67	2.32	2.29	2.42	5.46	1.29	1.28	3.09	1.24	1.16	2.84	1.1	1	2.24
L2	3.93	2.58	2.53	2.59	2.34	5.64	1.7	1.47	3.92	1.75	1.31	3.77	1.03	0.63	1.34
L3	6.01	3.52	3.6	3.91	2.87	6.1	3.64	2.57	5.45	2.11	1.16	3.07	2.43	1.32	3.1
L4	6.51	3.76	3.89	4.24	3.04	6.33	4.38	2.97	5.9	2.38	1.28	3.37	2.83	1.51	3.44
L5	12.75	11.11	9.5	10.8	11.43	12.93	13.3	14.04	14.26	11.79	10.56	12.27	11.15	8.55	10.11
L6	14.39	10.42	9.77	11.06	9.24	12.32	14.24	12.47	14.26	11.86	7.21	9.67	10.07	5.06	4.77
L7	17.41	10.69	10.67	12.66	7.97	10.97	15.94	11.13	13.74	12.4	6.16	5.75	13.41	6.63	5.7
L8	18.85	10.78	11.27	12.54	6.74	8.27	16.68	10.34	12.54	13.93	6.87	6.11	14.89	7.31	6.09
L9	41.35	40.6	34.1	39.05	40.07	37.62	42.87	43.17	37.93	40.3	38.21	32.78	40.93	39.65	33.58
L10	43.22	40.44	34.85	41.2	39.91	38.28	44.06	42.18	38.08	41.55	37.26	33.27	42.23	38.87	33.95
L11	46.14	40.99	35.65	44.71	40.54	39.92	46.86	42.21	40.08	43.75	37.28	33.48	44.95	39.5	35.04
L12	49.06	41.28	36.79	47.67	40.2	39.03	48.92	41.14	39.51	46.75	37.73	34.86	48.36	40.35	37.38
L13	6.99	12.59	26.41	6.61	11.22	23.34	7.98	13.16	29.6	7.05	12.58	26.48	6.67	12.16	26.13
L14	19.57	9.75	16.61	11.49	5.65	6.59	16.02	8.89	13.31	14.59	7.05	8.1	15.2	7.31	8.61
L15	51.97	48.24	2.53	46.6	40.7	3.41	56.63	48.75	3.55	56.67	51.09	3.76	49.97	47.88	3.77
L16	0.43	0.45	0.61	1.04	1.16	2.52	0.48	0.48	0.53	0.51	0.52	0.55	0.55	0.57	0.56
L17	15.61	8.28	0.93	8.29	4.31	3.07	11.51	5.92	2.74	12.46	6.35	3.37	13.36	6.84	2.65
L18	3.48	8.04	1.74	1.25	2.75	1.15	1.05	2.24	0.94	1.69	4.47	1.69	1.88	5.02	1.85
L19	2.27	1.21	9.9	3.33	3.18	10.49	3.16	3.29	12.26	2.82	2.38	10.49	2.78	2.11	10.63
L20	0.63	0.72	0.82	1.07	1.2	2.75	0.51	0.5	0.59	0.5	0.51	0.57	0.51	0.53	0.58

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L21	0.99	0.9	1.02	1.28	1.4	3.31	0.57	0.56	0.78	0.56	0.57	0.74	0.55	0.55	0.69
L22	2.21	1.68	1.52	1.7	1.84	4.28	0.83	0.8	1.51	0.78	0.75	1.4	0.78	0.72	1.27
GS0	74.49	76.99	64.23	80.55	83.59	67.49	74.8	77.64	65.21	74.35	75.99	64.04	73.99	77.02	64.68
GS1	69.74	72.98	61.25	76.5	80.55	65.67	69.32	72.6	61.04	68.44	69.86	59.01	67.47	71.34	61.57
GS2	60.68	63.49	53.82	61.98	65.7	56.54	58.99	61.84	52.53	57.81	58.39	49.6	57.58	60.21	52.29
GS3	53.82	56.39	47.11	53.15	56.82	49.74	52.59	55.37	46.09	51.31	52.06	43.38	51.22	53.35	46.62
GS4	46.51	48.57	39.7	44.61	48.12	42.32	47.12	49.86	40.36	45.08	45.53	36.82	45.15	46.72	38.55
GS5	40.22	41.99	34.43	37.48	41.21	36.03	41.27	44.21	36.29	39.65	40.48	33.42	40.28	41.5	33.84
GS6	34.8	36.27	29.52	31.52	35.16	31.06	36.73	39.54	32.34	34.99	36.03	30.05	35.86	36.74	30.75
GS7	29.89	31.12	25.02	26.86	30.4	26.74	32.07	35.15	29.59	30.58	31.9	26.41	31.34	32.26	26.11
GS8	25.91	27.17	21.67	23.07	26.92	23.97	28.34	31.59	26.58	27.02	28.99	23.57	27.62	28.87	23.05
GS9	22.5	23.68	18.78	19.66	23.4	20.76	24.74	28.18	23.53	23.74	26.05	20.92	23.91	25.4	19.84
GS10	19.44	20.5	16.24	16.78	20.4	18.6	21.3	24.73	20.77	20.42	22.85	19.1	20.93	22.51	17.53
GS11	16.17	17.09	13.43	14.3	17.67	16.25	17.7	20.99	17.95	17.06	19.56	16.54	17.37	19.17	15.4
GS12	13.32	14.09	11.03	11.89	14.88	14.32	14.56	17.62	15.57	14.09	16.61	14.51	14.41	16.25	13.01
GS13	10.62	11.21	8.93	9.39	11.79	12.29	11.56	14.36	13.55	11.18	13.47	12.8	11.1	12.45	10.91
GS14	7.92	8.32	6.65	6.31	7.98	9.87	7.46	9.35	10.55	6.91	8.37	9.67	6.74	7.52	8.22
GS15	5.97	6.3	4.98	4.48	5.48	8.11	4.2	5.12	7.7	3.81	4.53	7.05	3.4	3.79	5.47
GS16	4.33	4.55	3.65	3.09	3.83	6.66	2.3	2.76	5.39	2.13	2.57	5.06	1.84	2.14	3.96
GS17	3.38	3.55	2.79	2.38	2.93	5.59	1.43	1.62	3.8	1.37	1.63	3.52	1.13	1.31	2.38
GS18	2.59	2.73	2.16	1.92	2.34	4.9	0.96	1.06	2.12	0.98	1.11	2.08	0.85	0.95	1.44
GS19	1.72	1.79	1.47	1.46	1.69	3.94	0.66	0.67	1.06	0.69	0.74	1.05	0.64	0.68	0.86
GS20	1.12	1.14	1	1.18	1.34	3.12	0.57	0.57	0.72	0.53	0.55	0.67	0.54	0.56	0.63
GS21	0.93	0.95	0.81	1.15	1.28	2.81	0.54	0.54	0.63	0.58	0.59	0.64	0.53	0.54	0.56
GS22	0.78	0.8	0.77	1.12	1.25	2.74	0.56	0.56	0.65	0.52	0.54	0.58	0.53	0.54	0.55
GS23	0.49	0.51	0.73	1.08	1.19	2.53	0.56	0.56	0.67	0.54	0.54	0.59	0.55	0.55	0.62

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