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COLOR MODE CHANGE OF CATHODE - RAY - TUBE MONITOR

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ระบบการมองเห็นของคนเราทำให้มองเห็นสีจากจอภาพชนิดหลอดรังสีแคโทด หรือ CRT ในลักษณะของสีจากแหล่งกำเนิดแสง เมื่อลดความสว่างของจอภาพลงเรื่อยๆ สีที่ปรากฏบนจอภาพเริ่มเห็นในลักษณะคล้ายวัตถุหนึ่งในห้อง ทั้งนี้เพราะความสว่างของจอภาพต่ำลง จนความสว่างอยู่ในของเขตของ “การจดจำสภาพความส่องสว่างในพื้นที่ที่มองเห็น หรือ RVSI” ซึ่งของเขตดังกล่าวเป็นขอบเขตจำกัดของการ ปรากฏสีในโหมดสีวัตถุ (Object Color Mode) การทดลองนี้ทำขึ้นเพื่อหาขอบเขตความสว่างของ RVSI สำหรับสีทดสอบ 47 สี สีเหล่านี้คัดเลือกเพื่อให้ครอบคลุมขอบเขตสีที่จอภาพสามารถแสดงได้ ทำการทดลองภายใต้สภาวะความสว่าง 5 ลักซ์ และ 50 ลักซ์ ในการทดลองใช้การถดถอยเชิงเส้นในการปรับจอภาพ และใช้วิธีการแปลงแบบเมทริกซ์ในการแปลงค่าระหว่างพิกัดสี u’v’ และค่ารหัสสี RGB โดยพิกัด u’v’ ของสีทดสอบถูกแปลงสู่ค่ารหัสสี RGB เพื่อแสดงผลออกบนจอภาพ CRT ผู้สังเกตทำการปรับความสว่างของสีทดสอบเพื่อหาขอบเขตระหว่างสีโหมดวัตถุ และสีโหมดแหล่งกำเนิดแสง พบว่าค่าขอบเขตที่ได้จากการทดลอง มีค่าสูงเมื่อสีที่ทดสอบเป็นสีที่มีพิกัดสีใกล้เคียงกับสีของแหล่งกำเนิดแสงในห้องทดสอบ ค่าขอบเขตของสีเขียวมีค่าสูงกว่าสีแดง และสีน้ำเงิน ยังได้พบอีกว่าความสว่างของห้องมีผลต่อค่าขอบเขตโดยห้องทดสอบที่มีความสว่าง 50 ลักซ์ มีค่าขอบเขตสูงกว่าค่าขอบเขตที่หาได้จากห้องทดสอบที่สว่าง 5 ลักซ์ จากผลการทดลองพบว่า สภาพความสว่างของแหล่งกำเนิดแสงที่ใช้ในห้องมีผลต่อโหมดสีที่ปรากฏบนจอภาพ CRT นอกจากนี้ผลการทดลองยังแสดงให้เห็นว่า ความสว่างของสีที่ใช้ในการทดสอบเป็นปัจจัยหลักที่ใช้ในการพิจารณาค่าขอบเขตของ RVSI

ภาควิชา วิทยาศาสตร์ทางภาพถ่ายและเทคโนโลยีทางการพิมพ์ ลายมือชื่อนิสิต…………………………………………....
สาขาวิชา..เทคโนโลยีทางภาพ………….. ลายมือชื่ออาจารย์ที่ปรึกษา……………….……..……..
ปีการศึกษา….2545…………….………. ลายมือชื่ออาจารย์ที่ปรึกษาร่วม…………..………....

##4372257223: MAJOR IMAGING TECHNOLOGY
KEY WORD: COLOR APPEARANCE MODE / CRT DISPLAY / RECOGNIZED VISUAL SPACE OF ILLUMINATION / OBJECT COLOR / LIGHT SOURCE COLOR

NATHAPONG JANCHIDFAH: COLOR MODE CHANGES OF CATHODE–RAY–TUBE MONITOR. THESIS ADVISOR: ASSOCIATE PROFESSOR PONTAWEE PUNGRASSAMEE, THESIS CO – ADVISOR: ASSOCIATE PROFESSOR HIROYUKI SHINODA, Ph.D., 147 pp. ISBN 974 – 17 – 1191 – 3.

The human visual system normally treats the color from Cathode–Ray–Tube (CRT) displays as an attribute of light itself (light source color mode). By gradually decreasing the CRT luminance, the color on the CRT begins to appear more like an object placed in the room. This is because the luminance of the CRT becomes so low that the color appearance on the CRT goes inside the border of the Recognized Visual Space of Illumination (RVSI), which represents the limit of the object color mode. The experiment was conducted to investigate the border luminance of 47 colors. The colors were chosen to cover the monitor color gamut. These colors were displayed on a CRT monitor under two different illuminance levels, 5 lx and 50 lx. The CRT monitor was carefully calibrated using the linear regression method and the transformation matrix between u’v’ and RGB was obtained. Using this matrix, u’v’ of color stimuli was converted into RGB code value for the display. The task of observers was to set the luminance of color stimuli at the border between object and light source color mode. The border was found to be high in colors that have chromaticity-coordinates close to that of the illumination in the observer’s room. More saturated colors had lower border luminance. The borders at observer’s room illuminance of 5 lx were lower than those at 50 lx. The result implies that the color displays on CRT monitor can change their appearance depending on the illumination condition of the room. In addition, the result was shown that the brightness of stimuli works as the dominant factor to determine the border of RVSI

Department..Photographic Science and Printing Technology.. Student’s signature……….……………
Field of study..Imaging Technology………… Advisor’s signature……………………
Academic year…2002……………………….. Co-Advisor’s signature ………………

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Last but not least, I wish to express my deep gratitude to my parent for their love, inspiration, understanding and their endless encouragement and supports throughout this entire study, thanks for given my life.

Nathapong Janchidfah

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CHAPTER 1

INTRODUCTION

Cathode–Ray-Tube (CRT) based display systems are mainly used to view pictorial images. CRT display provides complex arrays of additive color, its produces them by stimulating red green and blue emitting phosphors.

The visual system normally treats the color from CRT as an attribute of light itself, light source color mode (perception of aperture color). While most of color in everyday life are object color mode (perception of surface color)[1]. The printed out, hard copy, photograph, etc. are also in the object color mode. The color appearance modes are different between color appearance on the CRT and on a printed picture. That means the color on a print can differ from that on CRT even their colorimetric values are same.

The research was conducted to solve the problem from the point of view of the Recognized Visual Space of Illumination (RVSI)[2,3]. It is hypothesized that the object color appearance changes to the light source color appearance when the appearance of the surface exceeds the size of the RVSI of observing room. In the experiment the color mode change is obtained by adjusting the luminance of CRT by used Visual Basic Programmed. It will indicate the border luminance of RVSI by measuring the transition point from object color to light source color.

By gradually decreasing the CRT luminance, the color on the CRT begins to appear more like an object place in the room. This is because the luminance on the CRT went inside the border of the RVSI, which present the object color mode.

This experiment was design to investigate the border luminance for 47 colors displayed on a CRT at the different illuminations of observer room 5lx and 50lx. The test colors chosen in u’ v’ color system by using matrix transform to RGB code value for display. It has been mentioned that the test colors are chosen to be covering the monitor color gamut. The relationship of the observer’s room and the border luminance of RVSI is the main propose of this research. The result will be avariable for the color management systems, serving as the information of condition to make the monitor profile in which get more consistent color appearance of CRT monitor. The result can be applied to setup the optimum lighting condition to ensure the color match between a picture on CRT and a picture printed out.

1.1 Objectives

To obtain the border of Recognized visual Space of Illumination (RVSI) by measuring the transition point from object color to light source color on CRT display.

1.2 Scope of the Research

This research approaches to indicates the border RVSI of colors that displays on the CRT monitor, which was measured the transition point from light source color to object color mode. The size of RVSI is also investigated by employing different illuminants of observer’s room 5 lx and 50 lx. The factors to determine the border of RVSI are next step test, by hypothesis that “the border luminance of RVSI is determined by brightness of stimuli", the Heterochromatic Brightness Matching [4] method were used.

In this research the matrix transformation from Y u' v' values to RGB values was created for the test colors chosen. In additional, for steady state to display, the optimum point of Brightness level and Contrast level of CRT were derived from the linear regression method and evaluated from the primary color (Red, Green, Blue) and neutral. CRT displayed the color stimuli, which used for the experimental will have steady primaries by this characterization adjustment.

1.3 Content of the thesis

This Thesis studies the color mode changes of CRT color monitor and this thesis consists of 5 chapters: Chapter 1 is an introduction of this thesis. Chapter 2 gives the explanation of theoretical considerations, such as the CIE System and color space, the CRT colorimetry, the color appearance mode and the concept of RVSI. Chapter 3 describes the experimental apparatus, subject task, experiment condition, the CRT characterization and the procedure of experiment. Chapter 4 gives the results and discussion on the border of RVSI of CRT color displays and the factors to determine the border of RVSI. In additional the results of CRT monitor characterization and brightness level adjustment are include. Finally, the results are concluded in Chapter 5 along with some suggestions.

CHAPTER 2

THEORETICAL CONSIDERATION AND LITERATURE REVIEWS

2.1 Theoretical consideration

The appearance of color is given by complicate process. The various parts of this process touch the domain of various sciences–physics, chemistry, physiology, and psychology. Thus, it is difficult to communicate about color. In order to obtain the effective in the color communication. It is necessary to study about color order system, the properties and mechanism of the component in color appearance process.

The color appearance of objects depends on three components, which are shown in the triangle of color in Figure 2-1

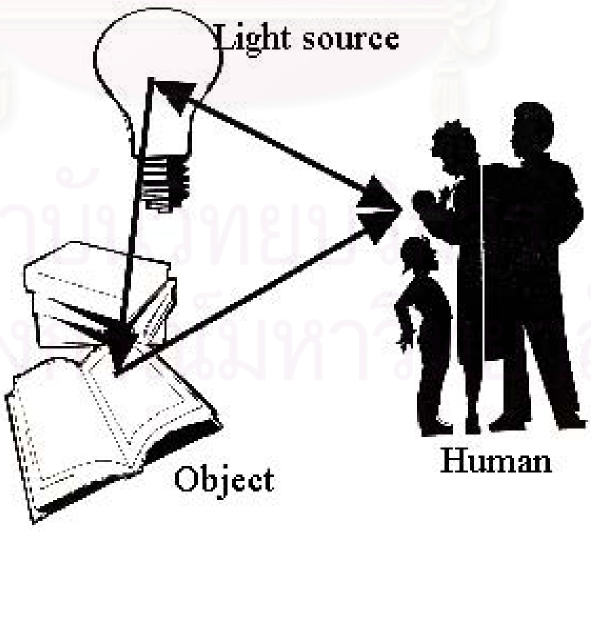


Figure 2–1 The triangle of color. Color exists due to the interaction of three components: light source, objects and the human visual system[5]

The first component is a source of visible electromagnetic energy necessary to initiate the sensory process of vision. The second component is an object, whose chemical properties modulate the electromagnetic energy. The third component is the human visual system. The modulated energy is imaged on the back of the eye, detected by photoreceptors in the retina, and processed by the neural mechanisms of human visual system to produce the perception of color. Note that the light source and visual system including both of eye and brain are also linked in Figure 2- 1. This is done to indicate the influence that the light source it self has strong effect on color appearance through chromatic adaptation, and so on.

The triangle of color in Figure 2-1 are required three components to produce color, they must also be quantified in order to produce a reliable system of physical colorimetry. Light sources are quantified through their spectral power distribution and standardized as illuminants. Material objects are specified by the geometric and spectral distribution of the energy they reflect or transmit. The human visual system is quantified through its color–matching properties that represent the first stage response (cone absorption) in the system [5].

In this chapter the explanations of the CIE system, which describes colorimetry, the definitions of color mode and the concept of the Recognized Visual Space of Illumination (RVSI), that can explain the color mode change phenomena and some color appearance effect will be given. Furthermore, the color mode change of CRT monitor was investigated in this experiment. The last part of this chapter includes explanations of additive mixtures of light and mathematics of color monitor technology.

2.1.1 The CIE System

The CIE Colorimetric System comprises the essential standards and procedures of measurement that are necessary to make colorimetry a useful tool in science and technology. The CIE system is usually employed in connection with instruments for color measurement. This system has been established by the Commission International de I' Eclairage, the French title of international committee, or International Commission on Illumination in 1931. The CIE system started with the premise developed on the human color perception process that stimulus for color is provided by the proper combination of a source of light, and an observer.

The fundamental aspect of color in CIE system concern with three factors. One factor is the relative spectral distribution of radiant flux emitted from a light source and incident on an object. The other two factors are the spectral reflectance factors of the object, and the color matching functions of the observer in viewing the object, as shown in Figure 2-2. Unlike the Munsell system, this system is not directly based on psychological scaling of color, but the color quantification.

In the CIE system, the stimulus of the brain or instrument interprets as a color is made up of the spectral power distribution curve of light source times the spectral reflectance or transmittance curve of an object times the spectral response curve of detector (here, the eyes). The CIE is introduced the element of standardization of source and observer, and the methodology to derive numbers that provide a measure of color seen under a standard source of illumination by standard observer [6].

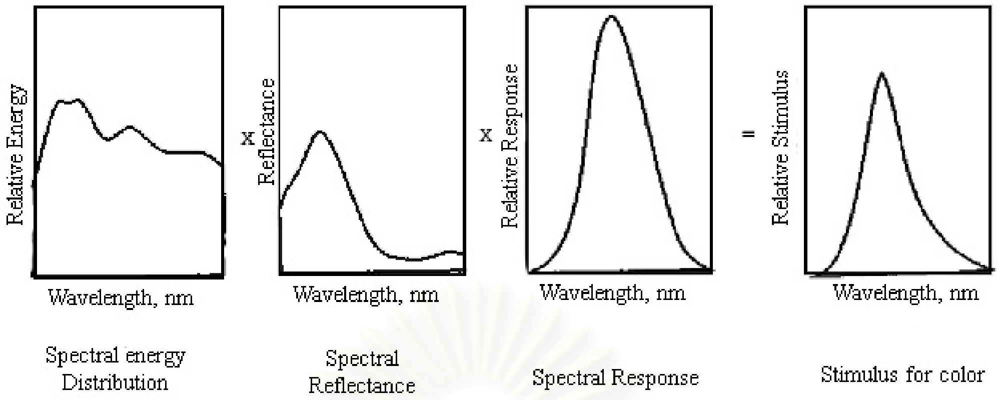


Figure 2 – 2 The stimulus that the brain or an instrument interprets as a color

2.1.2 Tristimulus Color Matching [7]

To exactly reproduce the color of a given object, it would at first seem necessary to have a multitude of light sources corresponding to all the different spectral colors and adjusts the intensity of each one separately until the objects spectrum was precisely duplicated.

In practice, however, equivalent color sensations can be produced by mixture of only three colors. This is because the analytical resolving power of eye for color poor, compared to the resolving power of other sense organs such as the ear or the nose; a complex light stimulus is perceived as a single sensation. In Figure 2-3 shows the experiment set up for a color matching experiment. Light is projected on to a diffuser, shown as a gray rectangle in this Figure, so that the observer sees a uniform single color. The unknown light to be matched, marked ‘?’, is viewed side by side with the three standard light, the intensities of which are individually varied until the colors are seen to match.

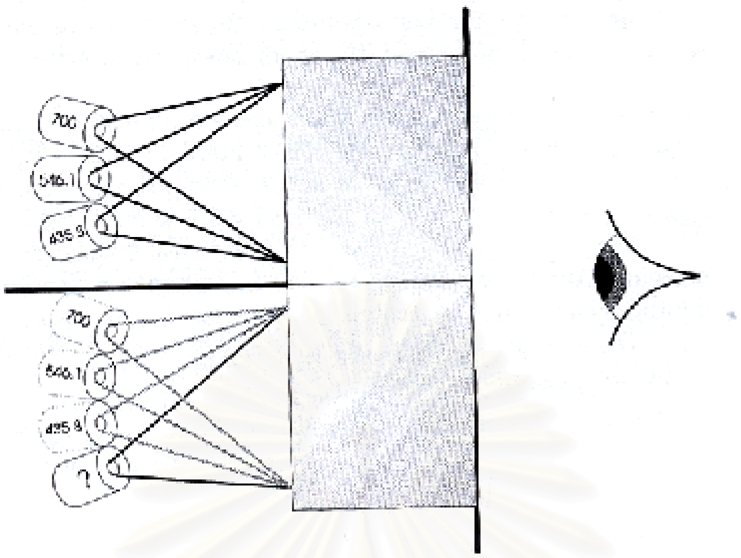


Figure 2 – 3 Trichromatic color matching

Three light often chosen for color matching experiments are monochromatic (single wavelength) source at 700 nm (scarlet red), 546.1 nm (yellowish green) and 435.8 nm (bluish violet), These are shown in Figure 2-3. The green and blue-violet lights correspond to sharp peaks in spectrum from a mercury vapour lamp; this allows calibration and exchange of experimental data between different sites. The red light is in an area of the spectrum where changes in wavelength and produces little change in perceived color, minimizing the effect of mis-calibration.

In some cassing, a match can only be obtained by adjusting the unknown color; this is done by add a proportion of one or more of standard light using a second set of standard lamps, This is equivalent to a negative quantity of one or more light being required. The specification of a color in term of the amounts of energy required from each of the three lights to match it is termed its TRISTIMULUS VALUE.

2.1.3 Standardized Observer

Based on a series of matching experiment, a standard observer was defined by international lighting committee (Committee Internationale de l' Eclairage, CIE) in 1931. This is a set of data which defines three primary colors for color measurements and states, for each wavelength interval, the amount of these primaries which would be required to match a spectrally pure color for a statistically normal (non 'color blind') observer. A graph of the matching functions is shown in Figure 2-4.

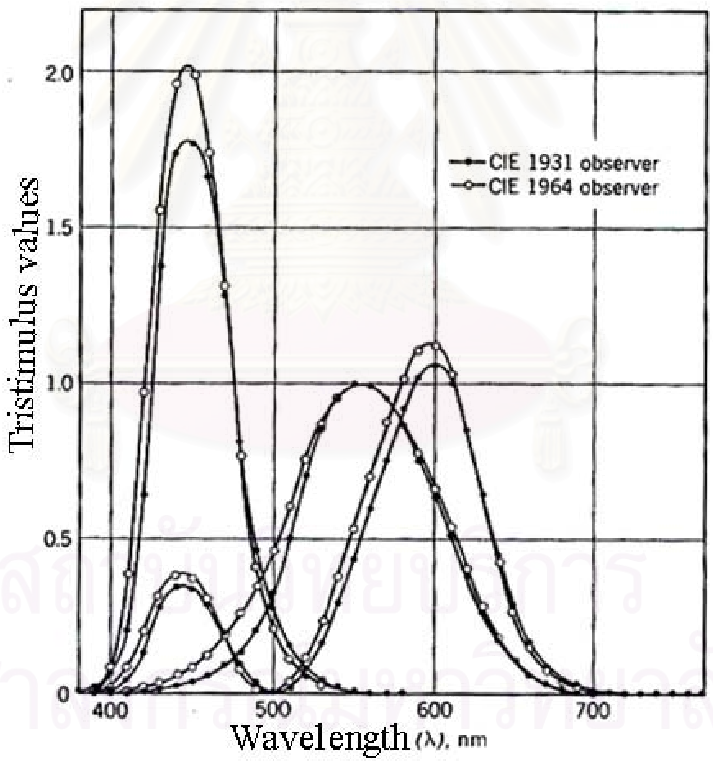


Figure 2 – 4 CIE color matching functions of the 1931 CIE Standard Observer and the 1964 CIE Supplementary Observers [7]

The three primaries are called $\bar{x}$, $\bar{y}$ and $\bar{z}$, A graph of the amounts of each CIE primary required to match any pure spectral color is called the matching function, and is shown in Figure 2-4. To match a particular color, a vertical line is drawn at that color's wavelength and the quantities read off from the intersections with each matching function. For example, to match the blue/violet color of wavelength 450 nm requires 0.33 units of $\bar{x}$, 0.04 units of $\bar{y}$ and 1.77 unit of $\bar{z}$.

The assumptions made in defining this observer were that the color subtends a visual angle of 2° or less and the illuminant is not too dissimilar to daylight. These are easy conditions to meet in practice. The restriction on angular size is so that the image of patch of color on the retina falls on the fovea, the area most sensitive to small changes in color. This is the usual situation when looking at a colored object. For those occasions - rare in practice – where wide field color specification is required, the CIE 1964 Supplemental Observer should be used. The experiments, which were performed to define the 1964 observer used a 10° field, so the resulting CIE vales are denoted $\bar{x}_{10}$, $\bar{y}_{10}$ and $\bar{z}_{10}$. The shape of the matching functions is broadly similar to 1931 Standard Observer, although tristimulus values calculated from two observers are different and should not be mixed. The comparison of color matching functions of the 1931 CIE Standard Observer and the 1964 CIE Supplementary Observer was shown in Figure 2-4 [8].

Because the standard observer is a mathematically defined set of functions, the results of color matching experiments can be simply calculated actually having to do the experiment. Color measurement can thus become an automated process.

2.1.4 Colored Objects [9]

There are two broad classes of color object, shown in Figure 2-5. Emissive objects produce their own light. Reflective objects, on the other hand, are totally dependent on an external light source; they provide a modification of the color of the illuminant by absorbing different amounts of light at different wavelengths. Fluorescent objects are a special case, in that they take in light at one wavelength and re-emit some of it at a longer, lower energy wavelength.

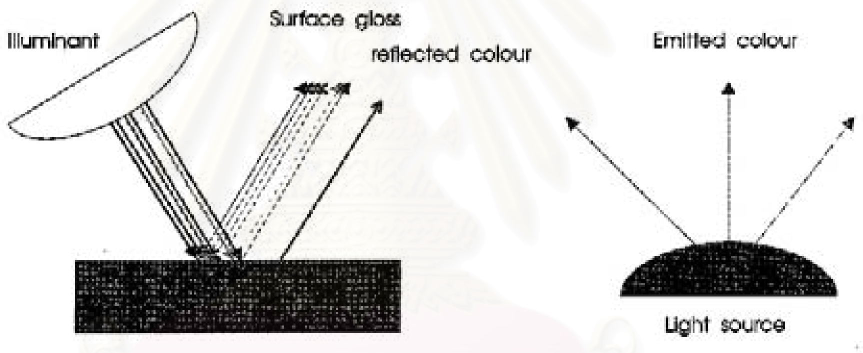


Figure 2 – 5 Reflective and emissive objects[8]

2.1.5 The CIE Chromaticity Diagram

The spectral energy distribution of a stimulus in either relative or absolute units, it is necessary only to multiply, wavelength by wavelength, by each of these curves, and summate or integrate separately for each function, to obtain numbers that represent the proper relative amounts of the three primaries to match the color matching function $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ defined in 1931 by CIE; also referred to as 2° XYZ tristimulus values. These three numbers were given the designation X, Y and Z.

They are suitable for viewing angle of 4° or less and are defined for reflecting objects by following formulas:

$$X = K\int_{380}^{780} S(\lambda)\ \bar{x}(\lambda)\ R(\lambda)d\lambda$$

$$Y = K\int_{380}^{780} S(\lambda)\ \bar{y}(\lambda)\ R(\lambda)d\lambda$$

$$Z = K\int_{380}^{780} S(\lambda)\ \bar{z}(\lambda)\ R(\lambda)d\lambda$$

$$K = \frac{100}{\int_{380}^{780} S(\lambda)\ \bar{y}(\lambda)\ R(\lambda)d\lambda}$$

Where, $S(\lambda)$: Relative spectral power distribution of illuminant.

$\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$: Color Matching function for CIE 2° Standard Observer(1931)

$R(\lambda)$: Spectral reflectance of specimen

Then the XYZ tristimulus values calculated to x, y, z according to formulas:

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

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

$$z = \frac{Z}{X+Y+Z} = 1- x - y$$

If the above formulas were used with X_{10}, Y_{10}, Z_{10} tristimulus values, the chromaticity coordinates would be x_{10}, y_{10}, z_{10} [10].

The procedure adapted by the CIE was so successful that it has become the universally recognized system for specification and measurement of color from the lighting industry to pigment manufacturing to psychological research in color perception. The CIE procedure converts the spectral distribution into three quantities Y, x, and y. The value Y gives luminance, which is a quantitative measure of the intensity of light leaving a surface. The perceptual attribute of “brightness” which is not quantitative, is closely relate to luminance and is frequently used in its place, though strictly speaking incorrectly. The two other coordinates x and y are the *Chromaticity Coordinates*, which locate the color (with respect to hue and saturation) on a two-dimensional color map called the *CIE Chromaticity Diagram*.

Two-dimension diagram on which the x, y chromaticity coordinate can be plotted as shown in Figure 2-6. In this figure, y is plotted as ordinate against x as abscissa, and this important diagram is usually referred to as the x,y chromaticity diagram. This diagram provides a sort of color map on which the chromaticities of all color can be plotted. As already mentioned, the equi-energy stimulus, S_E, has tristimulus value that are equal to one another, so that its chromaticity coordinate are x = 1/3, y = 1/3, and z = 1/3, and it is marked at this position in Figure2-6.

Although the x,y chromaticity diagram has been widely used, it suffers from a serious disadvantage: the distribution of the color on it is very non-uniform. Equal change in x, y or Y do not correspond to the same perceived difference. Many attempts have been made to provide a more uniform system. In each case the basic approach has been to start with the tristimulus value or chromaticity coordinates from CIE system and to transform these in some way to give a more uniform system.

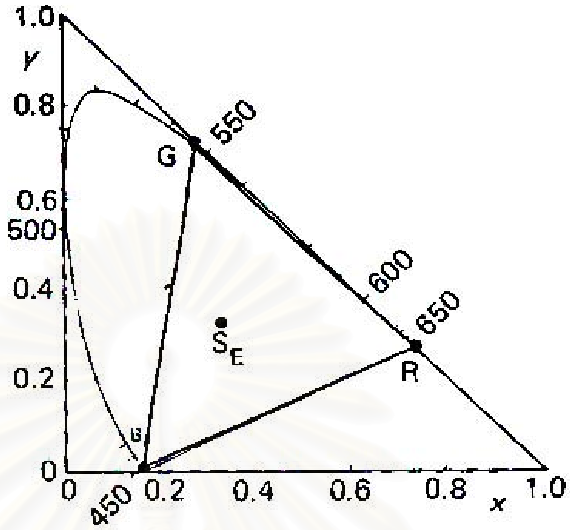


Figure 2 – 6 The CIE x,y chromaticity diagram. Show the spectral locus and equi-energy stimulus, S_E, and the CIE red, green and blue matching stimuli, R, G, B[11]

The formulae recommended by CIE in 1976, the uniform chromaticity scale (UCS). Defined by equations:

$$u' = \frac{4X}{X+15Y+3Z} = \frac{4x}{-2x+12y+3}$$

$$v' = \frac{9Y}{X+15Y+3Z} = \frac{9y}{-2x+12y+3}$$

The resulting diagram, shown in Figure 2-7. The CIE 1976 UCS diagram is intended to provide perceptually more uniform color spacing for color at approximately the same luminance [11].

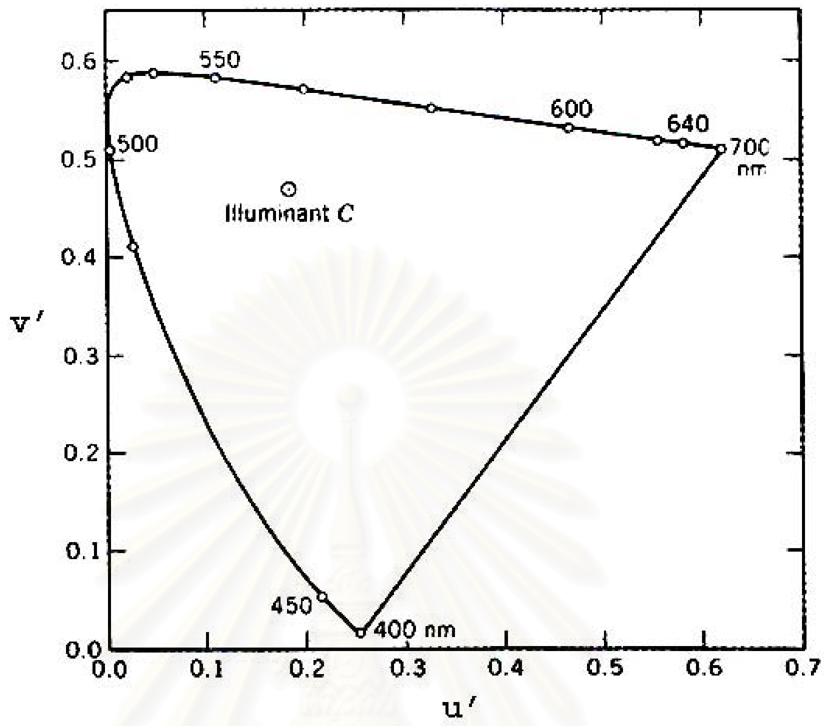


Figure 2 – 7 The CIE 1976 UCS (u', v') chromaticity diagram

2.1.6 CIE Standard Source and Illuminants [12]

The CIE distinguishes between sources and illuminants. Whereas a source refers to physical emitter of radiant energy, such as a lamp or the sun and the sky, an illuminant refers to a specific spectral power distribution incident on object viewed by the observer. The spectral power distribution which defines an illuminant may not necessarily be exactly realizable by source

The CIE recommends the following illuminants, defined by relative spectral power distributions shown in Figure 2-3. The CIE Standards include illuminants A, B, C, D and F:

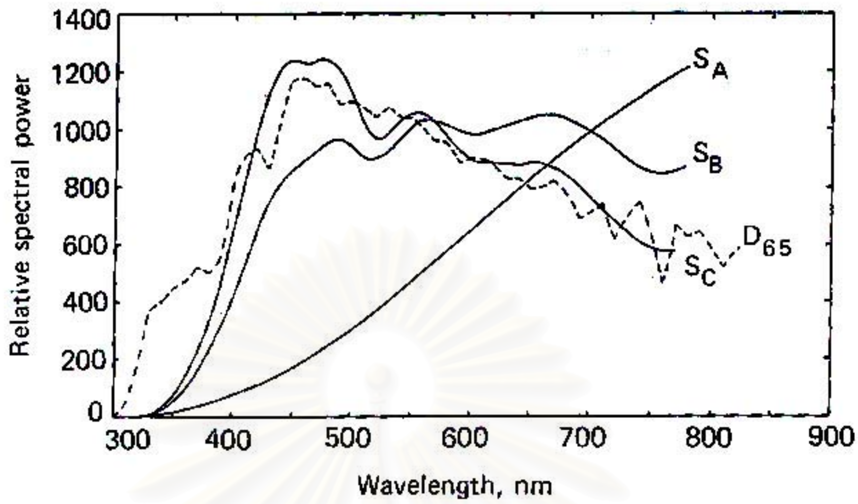


Figure 2 – 8 Relative spectral power distributions of standard Illuminants A(S_A), B(S_B), C(S_C) and D65 [13]

CIE Standard illuminant A

The plotted of the spectral energy distribution of illuminant A is shown in line S_A in Figure 2-8. Illuminant A represents a black body radiator at an absolute temperature of 2,856 K. Source A can be realised by a gas – filled coiled tungsten filament lamp operating at a correlated color temperature of 2,856 K. The energy distributions of source A and illuminant A can be very close if a calibrated lamp is used.

CIE Standard illuminants B and C

Illuminants B and C corresponded to different phases of daylight; the former is intended to represent direct sunlight with a correlated color temperature of 4874 K and the latter to represent average daylight with correlated color temperature of 6,774

K. The plotted of spectral energy distribution of illuminant B and C is shown in Figure 2-8. Standard Source B and C can be produced by used Standard Source A combined with a filter

CIE Standard illuminant D

It has been mentioned that daylight has lower ultraviolet content than black body radiators of the same correlated color temperatures. Therefore, in 1963, the CIE recommended a standard illuminant D to represent average daylight throughout the visible spectral energy distribution is also shown in Figure 2 – 8. Illuminant D65 has a correlated color temperature of about 6504 K and is one of a series of D illuminants representing daylights of different correlated color temperatures; these are designated D50, D55, etc., for example, for daylight having correlated color temperature at about 5000 K, 5500 K, etc., respectively. D65 is commonly used in colorimetric applications, while D 50 is often used in graphic arts applications.

CIE standard illuminant F [14]

CIE F illuminants represent typical spectral power distribution for various type of fluorescent sources. CIE illuminants F2 represent cool – white fluorescent with a correlated color temperature about 4,230 K. Illuminant F8 represent a fluorescent D50 stimulator with a color temperature of 5,000 K and illuminant F11 represent a triband fluorescent source with a color temperature of 4,000 K. Triband fluorescent sources are popular because of their efficiency, efficacy, and pleasing color - rendering properties .

Color Temperature and Correlate Color Temperature [15]

The spectral radiant power distributions were computed from Planck's formula and have been extended far above temperatures of furnaces actually measured. In Figure 2-9 the locus of chromaticities of Planckian radiators, the Planckian locus, is shown in the u',v' diagram [14].

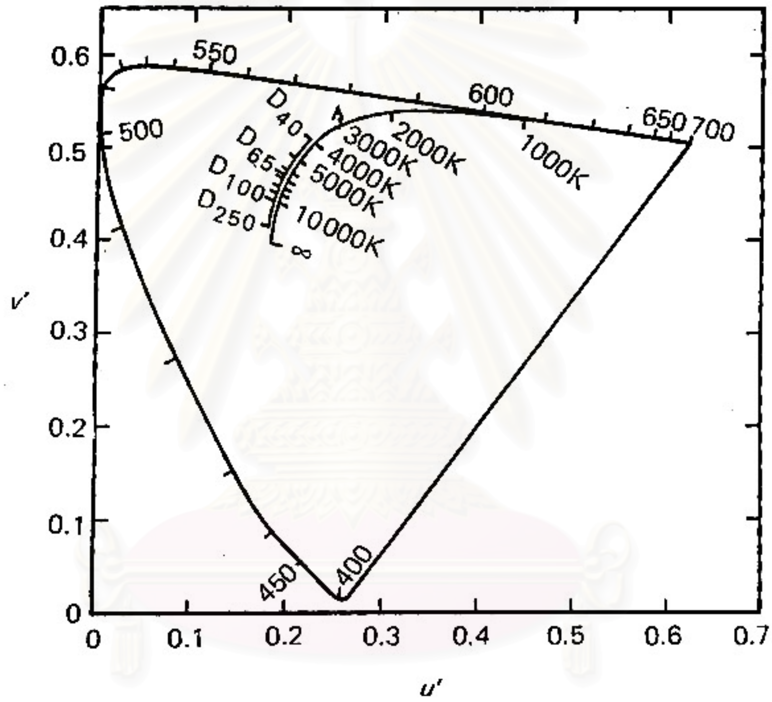


Figure 2 – 9 The loci of the chromaticities of Planckian radiators (Plankian locus) and CIE Illuminants (the daylight locus) in the u', v' diagram [15].

Many sources have relative spectral power distributions that are not quite the same as those of Planckian radiators, but are very similar. Tungsten filament lamps fall into this category. Such stimuli usually have chromaticities that are on the Planckian locus, and it is convenient, in this case, to characterize the color of the stimulus by quoting the temperature of the Plank radiator having the same chromaticity, and this is called *color temperature*.

2.1.7 RGB Color Space

This color space is commonly used, and corresponds to the input data for specific color CRT computer monitor. The three primaries are the particular color emitted by the three phosphors. It is therefore highly device specific, the same color will be specified as two different sets of number on two different monitors. The RGB color space is the device dependent color space, which defines color within a unit cube by additive – color – mixing model. Red, green and blue are additive primaries represented by the three axes of cube as shown in Figure 2-10; all other colors within the cube can be represented as the triplet(R, G, B), where values R, G and B are assigned in the range from 0 to 1. An important characteristic of the additive system is that the object itself is light emitter such as a television. Scanner and computer monitor also used RGB space. And RGB values in one device will not look like RGB value in another device [16].

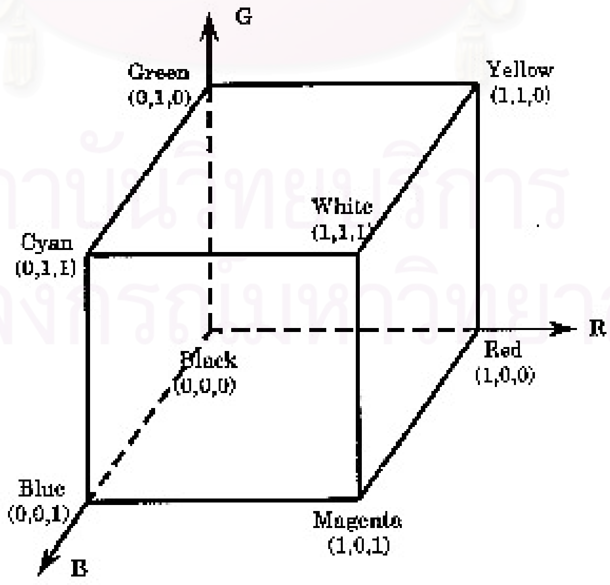


Figure 2 – 10 RGB color space

2.1.8 Color Monitors

The color monitor is an additive color system having RGB primaries. A generic computer – controlled CRT display system shown in Figure 2-11. A display interface card connects the computer to the monitor. This card has three major components: bus interface, display memory, and digital – to – analog converters (DAC) [17].

Images that seen on a color monitor begin as a grid of numbers, known as *Pixels* (“picture elements”). There are three sets of number corresponding to the red, green, and blue display channels. The digital information is stored in *frame buffer* (display memory). The numbers, called *digital counts,* usually expressed between 0 to 255 (i.e., $2^8 - 1$ for 8 bits – per – channel systems; in this case image are 24 bits), are first redefined through a look – up table (“video LUT’). Then, the redefine numbers are converted to video voltages that will eventually vary the intensity of each of three electron beams inside the cathode ray tube, they are greatly amplified. Each amplified signal controls a grid inside the CRT that repels one of the three electron beams. The modulated electron beams are accelerated toward the font of tube where phosphors are coated onto the inside surface.[18] As the electron beam strikes a phosphor, luminescent excitation and emission occur, resulting in colored light that can be seen.

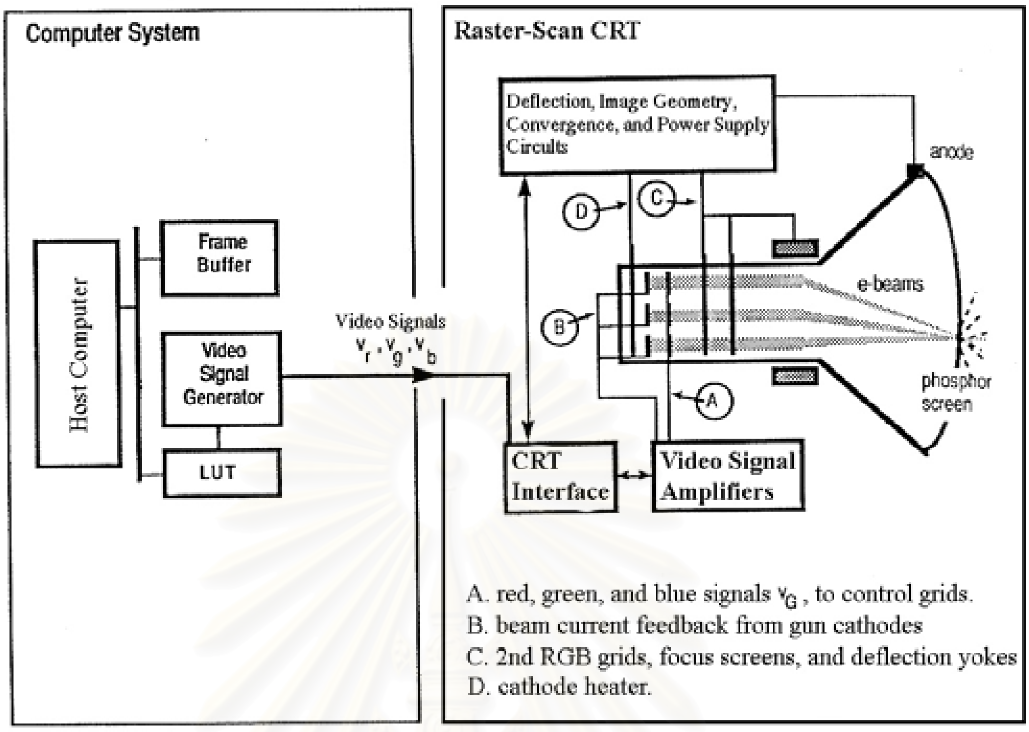


Figure 2 – 11 Schematic diagram of typical CRT display system [19]

2.1.8.1 Monitor Gamut

Producing different color by variable mixture of light from three-color phosphor is very similar to the color matching experiments except that:

- The light from the phosphors is not as saturated as pure spectral color
- Negative value cannot be applied to the guns.

These difference mean that some visible colors cannot be reproduced on CRT. The range of displayable color is termed the gamut and varies for different makes and models of monitor. It may conveniently be depicted on CIE 1976 USC diagram, where it forms a triangle bounded by monitor primaries. Each secondary lies on the line connecting the appropriate primaries, because the colors are additive. The white point should correspond to equal maximal output from the three guns. The example below (Figure 2-12) shows the gamut of monitor.

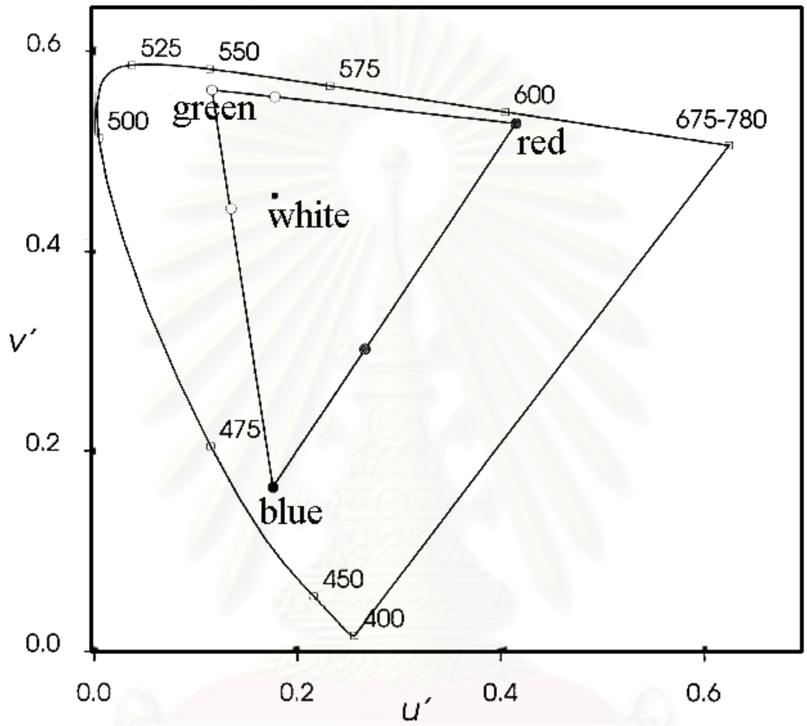


Figure 2 – 12 The gamut of CRT monitor on the CIE 1976 UCS diagram

The gamut of a monitor shrinks as the ambient light level increases, a fact which will be familiar to anyone who has tried to use a monitor in bright sunlight. Ambient light is reflected back from the monitor, adding white to all colors. This means that black becomes a dark grey. All colors move towards the white point, the darkest color moving most. So, as the ambient light level is increased, typically deep blues are lost first, and only the lightest colors such as yellow and white can still be seen at high ambient light levels [20].

2.1.8.2 Monitor Colorimetry

A very complex nonlinear equation can be written where each step between the input color plane and the final phosphor emission is accounted for. When measurements are made of each channel at its maximum emission as well as at reduced levels, the equation simplifies greatly, as shown on follow:

$$R = \left(k_{g,red}\left[\frac{LUT(d_{red})}{d_{max}} \right] + k_{o,red} \right)^{\gamma_{red}} \qquad \text{…Eq. (2-1)}$$

This equation describes the relationship between digital count in frame buffer (d_{red}) and the scalar of the additive color-mixing model (R) for the red channel. (Similar equations can be written for green and blue channels.) The digital counts defining an image (d_{red}) are redefined through an LUT, scaled by the maximum digital counts (d_{max}), amplified (k_g), biased (k_o), and accelerated nonlinearly (γ, called *gamma*). Once the electron beam is completely repelled, any further gun amplification or biasing will not change the scalar below zero. By definition the scalar cannot be negative. That is, R = 0 if Eq. (2-1) < 0, this equation assumes that the display has been set up reasonably. In particular, if black image is displayed (e.g., $d_{red} = d_{green} = d_{blue} = 0$), no phosphor emission occurs. Mathematically, k_o will always be equal to or less then zero. If emission occurs at 0 digital counts [21].

Because colorimeters are commonly used to measure display, the scalar is determined by calculating the ratio of a given level of emission to maximum emission:

$$R = \frac{L_r}{L_{r\,max}} \;,\quad G = \frac{L_g}{L_{g\,max}} \;,\quad B = \frac{L_b}{L_{b\,max}} \qquad \text{…Eq.(2-2)}$$

There are three parameters that affect the relationship between digital count and the scalars of each channel: gain, offset, and gamma. Gamma is an intrinsic property of the particular CRT and settings of video signal generator inside the computer and the gun-amplifier setting that by control varying a display's "contrast" and "brightness." For this reason, the colorimetry of display should be characterized for a particular computer and monitor display setting.

Thus, the relationship between display primaries and tristimulus values is linear, expressed by Eq.(2-3) :

$$X = RX_{r,max} + GX_{g,max} + BX_{b,max}$$

$$Y = RY_{r,max} + GY_{g,max} + BY_{b,max} \qquad \text{…Eq. (2-3)}$$

$$Z = RZ_{r,max} + GZ_{g,max} + BZ_{b,max}$$

Where X, Y, and Z are the tristimulus values of light produced by the visual colorimeter or CRT display; $X_{r,max}$, $X_{g,max}$,…, $Z_{b,max}$ are tristimulus values of each primaries at its maximum output; and R, G, and B are variables that define the amount of modulation of each primary. In mathematical terms, R, G, and B are Scalars. Matrix notation enables us to write Eq. (2-3) in more compact form, Eq. (2-4):

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} X_{r,max} & X_{g,max} & X_{b,max} \\ Y_{r,max} & Y_{g,max} & Y_{b,max} \\ Z_{r,max} & Z_{g,max} & Z_{b,max} \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \qquad \text{…Eq (2-4)}$$

Three matrices are used to describe the three equations forming Eq. (2-4): the tristimulus matrix of the mixture, the matrix of the tristimulus value of each primary, and the matrix of scalars. Eq. (2-4) is used to describe the colorimetry of computer controlled CRT displays. For many applications, one knows the tristimulus values and wants to determine the appropriate digital value. In this case, inverse equation is required:

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} X_{r,max} & X_{g,max} & X_{b,max} \\ Y_{r,max} & Y_{g,max} & Y_{b,max} \\ Z_{r,max} & Z_{g,max} & Z_{b,max} \end{bmatrix}^{-1} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \qquad \text{…Eq.(2-5)}$$

When a color system is describe by Eq.(2-4), the system has stable primaries. That is, the chromaticity coordinates of each primary do not change with the level of output. This is clarified by expanding the primary tristimulus matrix into a product of chromaticity matrix and a luminance matrix, shown in Eq.(2-6):

$$\begin{bmatrix} X_{r,max} & X_{g,max} & X_{b,max} \\ Y_{r,max} & Y_{g,max} & Y_{b,max} \\ Z_{r,max} & Z_{g,max} & Z_{b,max} \end{bmatrix} = \begin{bmatrix} (x_r/y_r) & (x_g/y_g) & (x_b/y_b) \\ 1 & 1 & 1 \\ (z_r/y_r) & (z_g/y_g) & (z_b/y_b) \end{bmatrix} \begin{bmatrix} L_{r,max} & 0 & 0 \\ 0 & L_{g,max} & 0 \\ 0 & 0 & L_{b,max} \end{bmatrix} \quad \text{...Eq.(2-6)}$$

Where x_r, x_g, …z_g, z_b are chromaticities for each primary and $L_{r,max}$, $L_{g,max}$ and $L_{b,max}$ are the maximum luminances of each primary.(Recall that $z = 1 - x - y$ and $Y = L = L_{r,max} + L_{g,max} + L_{b,max}$.)

Substitute the tristimulus matrix, Eq. (2-6) in to the CRT matrix tranform, Eq.(2-4).So that:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} (x_r/y_r) & (x_g/y_g) & (x_b/y_b) \\ 1 & 1 & 1 \\ \frac{(1-x_r-y_r)}{y_r} & \frac{(1-x_g-y_g)}{y_g} & \frac{(1-x_b-y_b)}{y_b} \end{bmatrix} \begin{bmatrix} L_r \\ L_g \\ L_b \end{bmatrix} \quad \text{...Eq. (2-7)}$$

These are the equations for calculating tristimulus X, Y and Z from chromaticities and luminance (L):

$$X = \frac{x}{y} L$$

$$Y = L \quad \text{...Eq. (2-8)}$$

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

By rearranging Eq. (2-7) and substitute the tristimulus value X, Y and Z , the luminances of each channel are calculated, Eq.(2-9).

$$\begin{bmatrix} L_r \\ L_g \\ L_b \end{bmatrix} = \begin{bmatrix} (x_r/y_r) & (x_g/y_g) & (x_b/y_b) \\ 1 & 1 & 1 \\ \frac{(1-x_r-y_r)}{y_r} & \frac{(1-x_g-y_g)}{y_g} & \frac{(1-x_b-y_b)}{y_b} \end{bmatrix}^{-1} \begin{bmatrix} \frac{x}{y}L \\ L \\ \frac{(1-x-y)}{y}L \end{bmatrix} \quad \text{…Eq.(2-9)}$$

The CRT colorimetry It consists of two stages: a nonlinear stage, where DAC values are converted to scalars, and a linear stage, where the scalars are transformed to CIE tristimulus value. The chromaticities do not vary with changes in a display's setup that are caused by adjustments of the gun amplifies's gain ("contrast") and offset ("brightness") or video look- up tables. However, the maximum luminance of each primary is very dependent on setup [22].

2.1.9 Color Mode [23]

Attribute of visual perception consisting of any combination of achromatic and achromatic content. This attribute can be described by chromatic color names such as yellow, orange, brown, red, pink, green, blue, purple, etc., or by achromatic color names such as white, gray, black, etc., and qualified by bright, dim, light, dark, etc., or by combinations of such names.

Perceived color may appear in several modes of color appearance. The names for various modes of appearance are intended to distinguish among qualitative and geometric differences of color perception. Some of the more important terms of the modes of color appearance are given in object-color, surface color, and aperture color.

Other modes of color appearance include film color, volume color, illuminant color, body color Each of these modes of color appearance may be further qualified by adjectives to describe combinations of color or their spatial and temporal relationships. Other terms that relate to qualitative differences among colors perceived in various modes of color appearance are given in luminous(perceived) color, non-luminous (perceived) color, related (perceived) color, unrelated (perceived) color.

Object color : Color perceived as belonging to an object.

Surface color : Color perceived as belonging to surface from which the light appears to be diffusely reflected or radiated.

Aperture color : Perceived color for which there is no definite spatial localization in depth, such as that perceived as filling a hole in a screen.

Luminous (perceived) color : Color perceived to belong to an area that appears to be emitting light as a primary light source, or that appears to be spectrally reflecting such light.

Note – Primary light sources seen in their natural surroundings normally exhibit the appearance of luminous colors in this sense.

Non – luminous (perceived) color : Color perceived to belong to an area that appears to be transmitting or diffusely reflecting light as a secondary light source.

Note – Secondary light source seen in their natural surroundings normally exhibit the appearance of non – luminous color in this sense.

Relate (perceived) color : Color perceived to belong to an area seen in relation to other colors.

Unrelated (perceived) color: Color perceived to belong to an area seen in isolation from other colors.

Light source color : The light source color is literally the color of light source.

2.1.10 Recognized Visual Space of Illumination (RVSI)[2,3]

The concept of Recognized Visual Space of Illumination, RVSI was proposed and developed by Prof. Ikeda. The concept of RVSI was introduced to express the state of an observer's recognition for a space in term of illumination. When one enters a room he/she almost instantly understands how the room is illuminated, brightly or dimly, or whitely or a little bit reddish, and so on. This state is expressed as he/she obtained the RVSI in his/her brain, which was constructed based on what he/she saw first in the room, namely the objects, windows and luminaries, which we call the initial visual information. If the surfaces of the objects appear very bright, he/she recognizes that the room is very brightly illuminated and we express the state as that the size of his/her RVSI is large. When all the object appear to him/her a little bit reddish because of the incandescent light source, for example, he/she understands that the room is a little bit reddish illuminated. We express the state as that the color property of the RVSI is a little bit reddish.

Once the RVSI is established, the lightness and color of objects in the room are judged in relation to RVSI. In other words the appearance of objects and the RVSI must be in accordance with each other If the appearance of an object is too bright compared to the size of the RVSI, the observer feels it is somewhat unnatural and experiences a contradiction. To resolve this condition, the observer concludes that the object is locally illuminated in addition to the main lighting or that the object itself is radiating light, which results in the perception of light source color. If the appearance of the object is within the size of the RVSI, the observer feels it to be natural, and perceives there the object color and can assess its lightness in relation to the size of the RVSI[24].

2.1.11 The relationship between the size of the RVSI and the object color and the light source color .

The RVSI is represent by a circle and its brightness size by the radius. An object in the space can be represent by a point within the circle. The lightness of an object is represent by the distance from the center along the radius. A scheme of the assessment of the lightness is illustrated in Figure 2-13. The object is included inside the RVSI and it gives the object color of certain lightness, high when it is near the circumference and low when it is near the center. The object appear as the light source when it is plotted outside the circle. On the other hand, it can expressed by a sphere of which radius represents the brightness size of the RVSI. If the local illuminance on the color stimulus is low as indicated by C_o the luminance of the color stimulus inside the sphere or a circle for simplicity and the surface exhibits the object color mode. The appearance reaches the border as shown by C_b and then shifts further outside to the position C_u which results with unnatural appearance. The final appearance is the light source color mode by C_l .

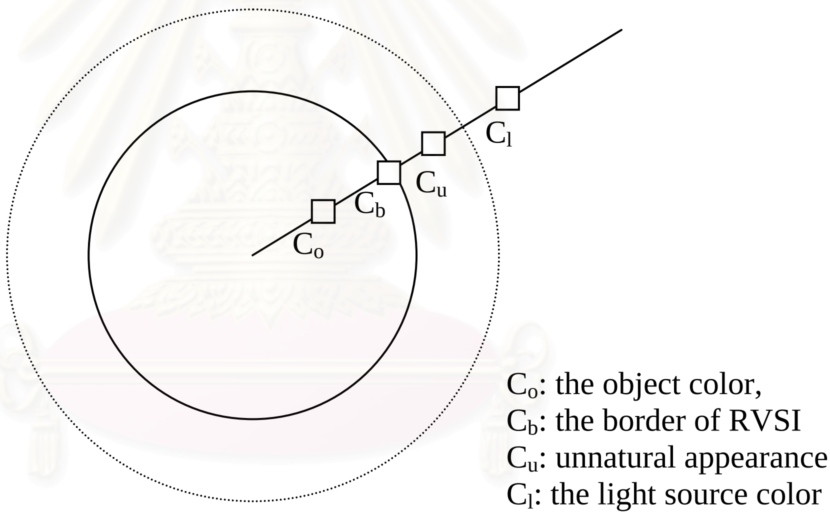


Figure 2-13 A scheme showing the determination of apparent lightness

The investigate of the color appearance mode is important because it tell us about the mechanism of visual system for color perception on one hand and gives us some knowledge about lighting effect in environment on the other[2,3,24].

2.2 LITERATURE REVIEWS

One of method to express the color appearance mode change is the concept of Recognized Visual Space of Illumination, RVSI. This method was propose and developed by Prof. M. Ikeda et. al [2,3,24], in there experiment they illuminate the test chart by projector. In observer room was illuminate by usual ceiling lamps. The appearance of color chart placed with in the hidden illumination was judged referring to the already constructed RVSI for the room. From this experiment they can find out the border of RVSI, the upper limits of color appearance in the object color mode. By increase the hidden illumination on test chart.

In the experiment of Y.Yamauchi et. al[25], they investigated effect of chromaticity of test stimuli for the surface color mode perception. The test stimulus was presented with CRT monitor and the surrounding stimulus was presented either with Munsell color chip or with a CRT monitor. The result showed that the upper limits of the luminance differ depending on the chromaticity of the test stimulus. Their result suggested that brightness determined the mode perception, and brightness matching test stimulus may work as a determining factor.

In there experiment(M.Ikeda et. al. and Y.Yamauchi et. al.) shown that the upper limits of luminance for stimulus appear in object color mode was obtain. But in high upper limits of the luminance for test stimulus, they did not observed. However, increase the luminance may change the appearance mode from surface color mode to aperture color mode(light source color mode). Y.Thiangtangtum[26], she used projector to hidden luminance on the color charts. She found that, when the luminance of test charts in limit of border the color appear like an object place in the room(surface color mode). For further increase of luminance, the surface began to appear unnatural as an object in the room. The final appearance was the light source color(aperture color mode) when increase luminance. She concluded that the color of test stimuli change from object color mode to light source color mode when the luminance of test stimulus higher then the illumination of observer room. In another hand the test chart appear in light source color mode when its exit the border of RVSI.

The color that displayed on the CRT monitor was wide interesting for many researches. The factors influencing the appearance of CRT colors are observed in the experiment of D. H. Brainard et. al[27] . They found that the color appearance of CRT depends on the context in which it is view. The result concludes that the color displayed changes their appearance with two main factors, one is the monitor context, color surrounding the test stimulus influencing the simultaneous color contrast. The other is the illumination context, the ambient illumination influencing the color constancy. The visual system adapts to the ambient illumination to keep surface color approximately constant. About the effects of ambient illumination on the appearance of CRT colors are more study by M. Melgosa et al.[28] in America and by H. K.Choh et al.[29] in Korea. The experiment was done under variant illumination context such as F2, F8, and F5 fluorescent light type. They conclude that the chromaticity of the achramatic color was shifted toward that of the illuminant, which implies the change of the observer’s chromatic adaptation state. The result found that the shift ratio were increased according to the increased of the of the distance between chromaticity of CRT white and those of illumination and increased according to the increase of luminance level of the illuminance.

The Appearance of CRT colors may appear in several modes of color appearance. In the experiment of H. Shinoda et. al[30], they were made for structure of categorized color space in the aperture and surface color modes. The color appearances of two modes were reproduced on a CRT display with or without a surround configuration. The result indicated that the color appearance change more largely with luminance in the surface color mode then in the aperture color mode. Further more they presented that in aperture color mode the color is categorized by only chromaticity but by luminance and chromaticity in surface color mode.

In the previous experiment as shown by some researchers. They found the relation between color appearance mode change and illumination of observer room. In main propose of this experiment want to find the relationship of observer room illumination and appearance color modes of the CRT colors by using the RVSI to determine. The result will be implement in a monitor profile for a color management system to get more consistent color appearance of the CRT, which is view under various ambient illuminations.

CHAPTER3

EXPERIMENT

3.1 Apparatus

3.1.1 Colorimeter Minolta CL – 100

3.1.2 Spectrophotometer Spectrascan PR 650 of Photo Research

3.1.3 CRT monitor LG 550D 15”

3.1.4 Experimental booth

The experimental booth has two rooms, the observer’s room (OR) and the test room (TR), as shown in Figure 3-1 (a) and (b) the size of OR is 1m wide, 1.5m long and 2.4m high. The room is decorated as a normal living room. The shelves and walls are decorated with artificial flowers, dolls, books, framed picture and others. The colors of these objects were selected so that they cover various hues. The room was illuminated by the fluorescent lamps of the daylight type FL and they were controlled by a rotary switch so that the room illuminance was adjusted at any level. The illuminance was measured by the colorimeter Minolta CL - 100 placed on a table as seen in Figure 3-1.

The size of TR is 1.3m wide, 1.5m long and 1.8m high. The entire test room is covered with a black cloth to prevent light coming from outside. The size of the rectangular aperture made between the room is 2cm x 2 cm, 1° viewing angle, and its is located at the high 126.5 cm., at the observer's eye level.

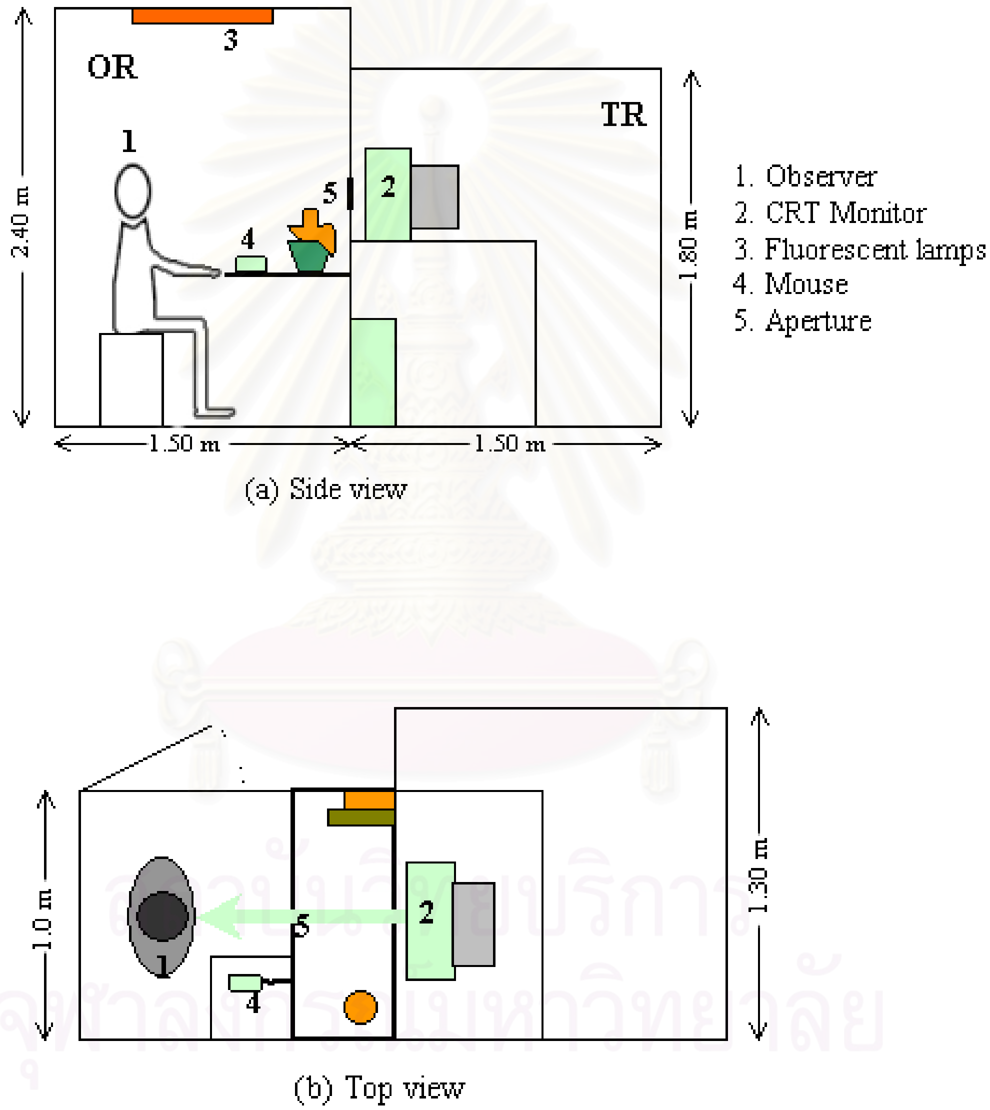


Fig 3-1 The experiment booth (a) side view and (b) top view

A subject sat in OR and consequently he/she constructed a RVSI in his/her brain for this room. A subject could see through the aperture a stimulus displayed on CRT that installed in TR. The subject saw the stimuli it appeared as if it was pasted on the aperture.

Subject in the OR can be operated the luminance of color display on CRT using mouse. The luminance (Y) and u' v' of color on CRT will be measured with a spectrophotometer of Spectrascan PR650, have to be measured direct to the monitor from the OR. To display the stimuli by using the interactive program built by Visual Basic Version 6.

The font view of the OR was shown in Figure 3-2 and the specification of the CIE Yu'v' of objects in OR were shown in Table 3-1. The color was displayed to the subject as the test stimulus, the subject can be seen through the rectangular aperture, which made on the wall of OR. The subject could be adjust the luminance of CRT (test stimulus) from this room.

In the Brightness Matching experiment, for the white reference the card of the aperture (No. 14 in Figure 3-2) was replaced by another card on which an achromatic N7 chart of the same size as aperture. The N7 achromatic chart was pasted at the right side of aperture with a separation of 2mm.

Figure 3-2 Font view of the observer's room

Table 3-1 The CIE Yu'v' of objects in the Observer's room

No.	Y(cd m^{-2})	u'	v'	No.	Y(cd m^{-2})	u'	v'
1	1.02	0.218	0.495	8	0.81	0.219	0.501
2	1.44	0.215	0.492	9	0.14	0.190	0.504
3	0.08	0.154	0.552	10	0.29	0.210	0.475
4	0.29	0.341	0.501	11	0.85	0.250	0.514
5	0.31	0.247	0.546	12	0.17	0.427	0.518
6	0.15	0.224	0.440	13	0.85	0.238	0.528
7	0.24	0.251	0.535	14	0.91	0.217	0.494
N7	0.55	0.215	0.490				

3.2 Subject

6 Subjects (2 males and 4 females) with no deficiencies in color vision took part in the experiment. They were students and employee of the department of imaging technology with deference level of expertise in color imaging and psychophysical scaling;

- NJ (25 years old, male, Thai)
- PP (24 years old, female, Thai)
- PS (25 years old, male, Thai)
- WU (24 years old female, Thai)
- KJ (22 years old, female, Thai)
- YT (25 years old, female, Thai)

Each subject repeated the determination for each test chart for ten times as separated session for both the border and brightness matching experiments.

3.3 Illumination Conditions

Two level of ambient lighting used in the experiment: first 5 lux lighting by fluorescent lamps of daylight type. The CIE chromaticity coordinate of source was (u’,v’) = (0.207, 0.487). The other was 50 lux, lighting by fluorescent lamps of daylight type, (u’v’) = (0.209, 0.488). The ambient light in observer’s room had the color temperature of about 5000K.

3.4 CRT Test Stimuli

3.4.1 Monitor Characterization

The LG-550D RGB monitor served as the CRT display for presenting the stimuli and was driven by a PC with 16 bit video board. The techniques to set the optimum level of brightness have been summarized by Seung –Ok et al.[31] From these techniques, applied to A 15” LG 550D monitor. The optimum brightness level could be found by measuring a few tones of neutral for the combination of 3 levels of brightness and 2 levels of contrast.

The propose of this techniques was to setup the monitor in the standardized of CIE, the colorimetry of CRT were predicted by mathematical model such as the linear equation and matrix transform.

3.4.2 Test Stimuli Selection

The experiment was performed with a set of 47 colors displayed on the CRT monitor. Firstly, the colors were chosen in the u’v’ diagram and transformed to the scalar value by the matrix, so that, they uniformly cover the CRT color gamut. Then the scalar values converted to the RGB values by the non-linear equation with the system parameter. The RGB value are use to display the test color on monitor. The chromaticity diagram of the 47 test stimuli was show in Figure 3-3, the test stimuli were plotted in u’v’ diagram (CIE 1976 UCS). Their chromaticity coordinates are shown in Table 3-2. The RGB code value and their maximum luminance of the color stimuli shows in Appendix A.

Table 3-2 The CIE chromaticity coordinate of the 47 stimuli

Color No.	x	y	u'	v'	Color No.	x	y	u'	v'
1	0.329	0.537	0.150	0.550	25	0.252	0.272	0.175	0.425
2	0.409	0.500	0.200	0.550	26	0.309	0.260	0.225	0.425
3	0.259	0.483	0.125	0.525	27	0.361	0.248	0.275	0.425
4	0.339	0.452	0.175	0.525	28	0.409	0.238	0.325	0.425
5	0.409	0.424	0.225	0.525	29	0.208	0.246	0.150	0.400
6	0.471	0.400	0.275	0.525	30	0.265	0.235	0.200	0.400
7	0.527	0.378	0.325	0.525	31	0.317	0.225	0.250	0.400
8	0.577	0.359	0.375	0.525	32	0.365	0.216	0.300	0.400
9	0.276	0.408	0.150	0.500	33	0.223	0.213	0.175	0.375
10	0.346	0.385	0.200	0.500	34	0.276	0.204	0.225	0.375
11	0.409	0.364	0.250	0.500	35	0.324	0.196	0.275	0.375
12	0.466	0.345	0.300	0.500	36	0.185	0.192	0.150	0.350
13	0.516	0.328	0.350	0.500	37	0.237	0.184	0.200	0.350
14	0.563	0.313	0.400	0.500	38	0.285	0.177	0.250	0.350
15	0.289	0.349	0.175	0.475	39	0.201	0.166	0.175	0.325
16	0.352	0.330	0.225	0.475	40	0.248	0.160	0.225	0.325
17	0.409	0.314	0.275	0.475	41	0.293	0.154	0.275	0.325
18	0.461	0.299	0.325	0.475	42	0.214	0.143	0.200	0.300
19	0.508	0.286	0.375	0.475	43	0.259	0.138	0.250	0.300
20	0.237	0.316	0.150	0.450	44	0.182	0.127	0.175	0.275
21	0.300	0.300	0.200	0.450	45	0.226	0.123	0.225	0.275
22	0.357	0.286	0.250	0.450	46	0.196	0.109	0.200	0.250
23	0.409	0.273	0.300	0.450	47	0.167	0.095	0.175	0.225
24	0.457	0.261	0.350	0.450					

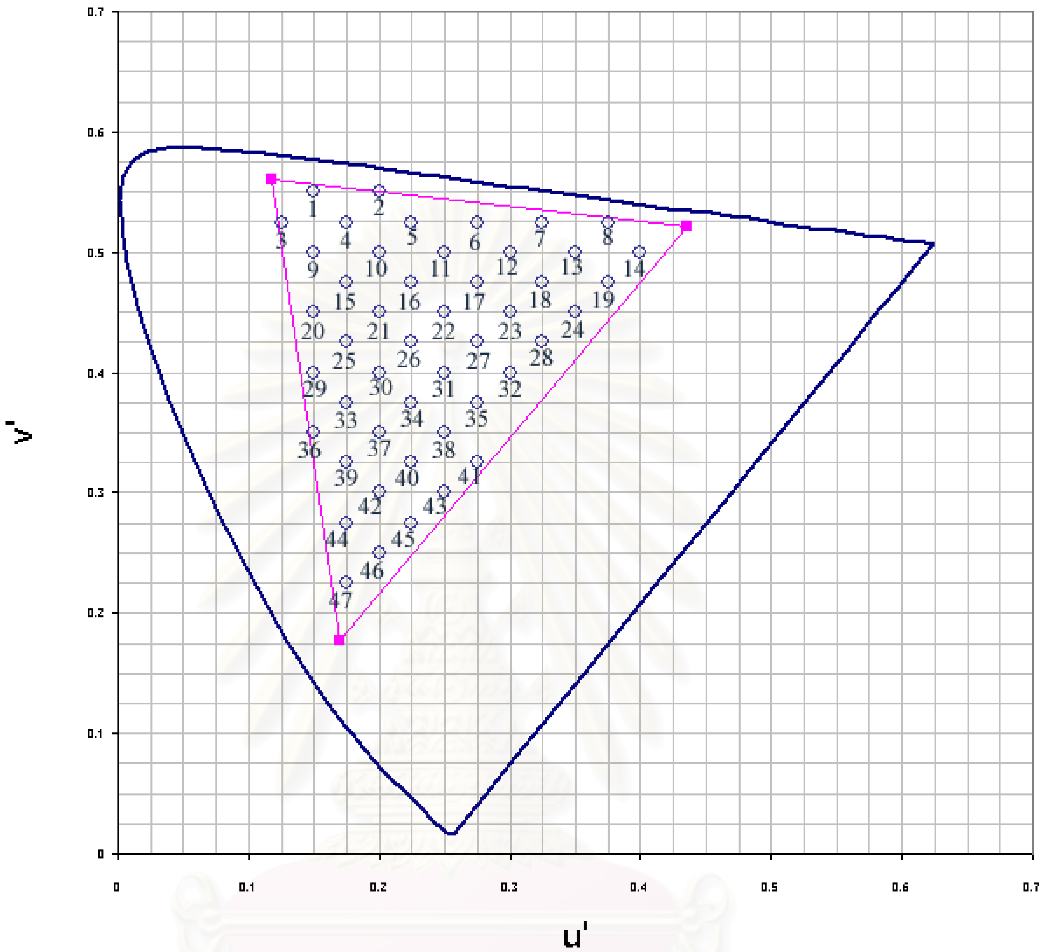


Figure 3-3 The chromaticity coordinate of 47 stimuli plot on Lu'v' UCS diagram

3.4.3 Display of Color Stimuli

The color stimuli were display on a CRT color monitor by using the executed file for controlling the CRT monitor. The executed file can operate the CRT to display color by input Red, Green and Blue code values. It is an interactive program, the observer can adjust the color with mouse or keyboard. The programmed file can increase and decrease brightness of color or luminance of CRT while the chromaticity is kept constant. However the color consistency of CRT depended on physical properties of each monitors. The user interface of program was show in Figure 3-4 and the source code of program in Appendix B.

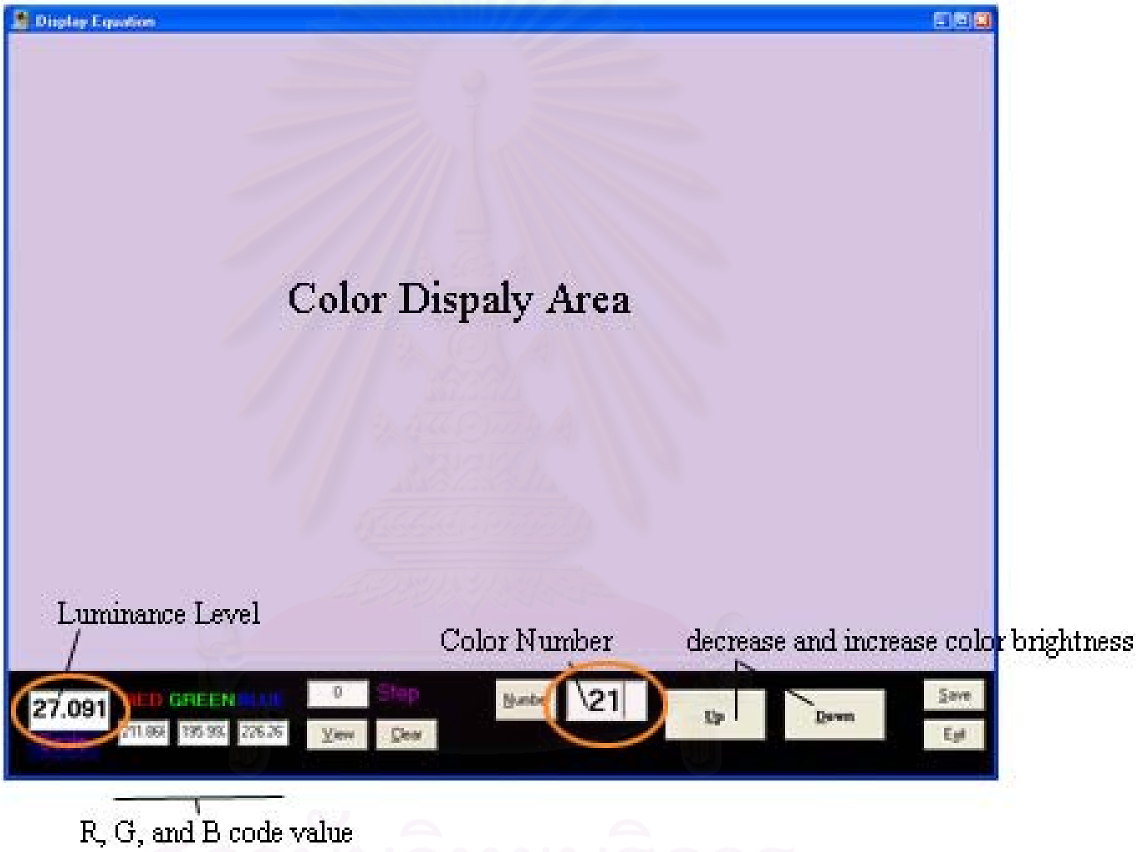


Figure 3-4 The user interface of Programmed file, used for stimuli presentation in the experiment

3.5 Experiment Procedure

3.5.1 The Border of RVSI Experiment

An observer was invited into the observer's room where the room illuminated at 5 lux (50 lux for the 2nd condition). When the observer sat on an appropriate position let to adapt in that light condition for minutes. One was instructed to look at the color stimuli through the square aperture on the wall. The observer adjusted the luminance or CRT (brightness of color stimuli) via a mouse or a keyboard. The observer increased the lightness slowly until the appearance of the color reached the transition point, which it starts to appear unnatural as an object in the room. It was luminous or transparent color. The observer would stop increment of the luminance at this point. The data was collected.

The experiment was repeated ten times for each test stimulus in separated sessions. The data of six observers were collected then the border luminance of RVSI was obtained by calculation.

3.5.2 Brightness Matching

The transition point of color stimuli from the object color to light source color mode was obtained as a border of RVSI. It is interesting to investigate what was determining the transition point. The most probable factor is the brightness of the test stimulus. If the color stimuli reach certain brightness then it might change from the object color to the light source color. In ordere to investigate this hypothesis, the brightness of stimuli was measured by using the Heterochomatic Brightness Matching method.

In this method a reference white chart of N7 was pasted on right-hand side of the aperture for test color stimuli. The arrangement was shown in Figure 3-5. The observer compared two targets and adjusted the luminance of CRT test colors, so that both targets appeared the same in “Brightness”. The luminance of CRT display was collected. This operation was done for all 47 colors stimuli used in the main experiment. The brightness matching was repeated ten times for each color. These matched luminance data collected from the same observer as in the border experiment.

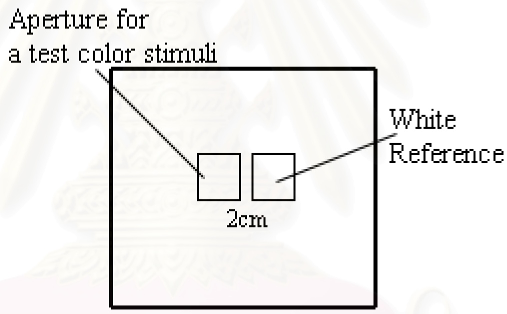


Figure 3-5 A reference white chart of N7 was pasted on the right-hand of the aperture for the test target color.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Monitor Characterization

4.1.1 *The Optimum Brightness level*

CRT color monitors produce an image with the light emitted by red, green, and blue phosphor. The quality of the image depends on the nonlinear relationship between the amount of emitted light and the DAC count applied to RGB channels.

The results of measurement for setting optimum brightness level of the LG 550D are described as follow. First, tested the change of gamma (γ) according to brightness and contrast control in LG 550D monitor. For 35 combinations of 5 levels of brightness (30, 40, 50, 60, and 70) and 7 levels of contrast (20, 30, 40, 50, 60, and 70), 5 neutrals from back to white were measured form the tone reproduction curves. Using linear regression for calculate the gamma, it was found that at contrast level of 50 % and above the average γ converged to a particular value. This value would be expected as an inherent gamma coefficient for RGB channel.

Next, the luminance of 6 tones of neutral: (47, 47, 47), (63, 63, 63), (79, 79, 79), (95, 95, 95), (111, 111, 111) and (255, 255, 255) was measured. Six settings were selected out of combination of three levels of brightness, (30, 50, 70) and two levels of contrast (50, 70). The measured data are shown in Table 4-1, and their normalized luminances are shown in Table 4-2. The plotted of these normalized data show in Figure 4-1.

Table 4-1 The measured of luminance of neutral at 3 different brightness level

Normalized DAC (DAC/255)	Brightness 30%		Brightness 50%		Brightness 70%	
	Contrast 50%	*Contrast 70%*	*Contrast 50%*	*Contrast 70%*	*Contrast 50%*	*Contrast 70%*
(47,47,47)	-	-	-	0.46	1.42	1.90
(63,63,63)	-	-	0.45	0.86	1.95	2.77
(79,79,79)	-	0.17	0.76	1.49	2.61	3.88
(95,95,95)	-	0.60	1.16	2.32	3.34	5.20
(111,111,111)	0.34	1.10	1.65	3.35	4.18	6.69
(255,255,255)	6.24	14.70	10.90	22.00	17.00	30.10

Table 4-2 The normalized of luminance data for 3 different brightness level

Normalized DAC (DAC/255)	Brightness 30%		Brightness 50%		Brightness 70%	
	Contrast 50%	*Contrast 70%*	*Contrast 50%*	*Contrast 70%*	*Contrast 50%*	*Contrast 70%*
0.184	-	-	-	0.021	0.084	0.063
0.247	-	-	0.041	0.039	0.115	0.092
0.310	-	-	0.070	0.068	0.154	0.129
0.373	-	-	0.106	0.105	0.196	0.173
0.435	0.054	0.075	0.151	0.152	0.246	0.222
1.000	1.000	1.000	1.000	1.000	1.000	1.000

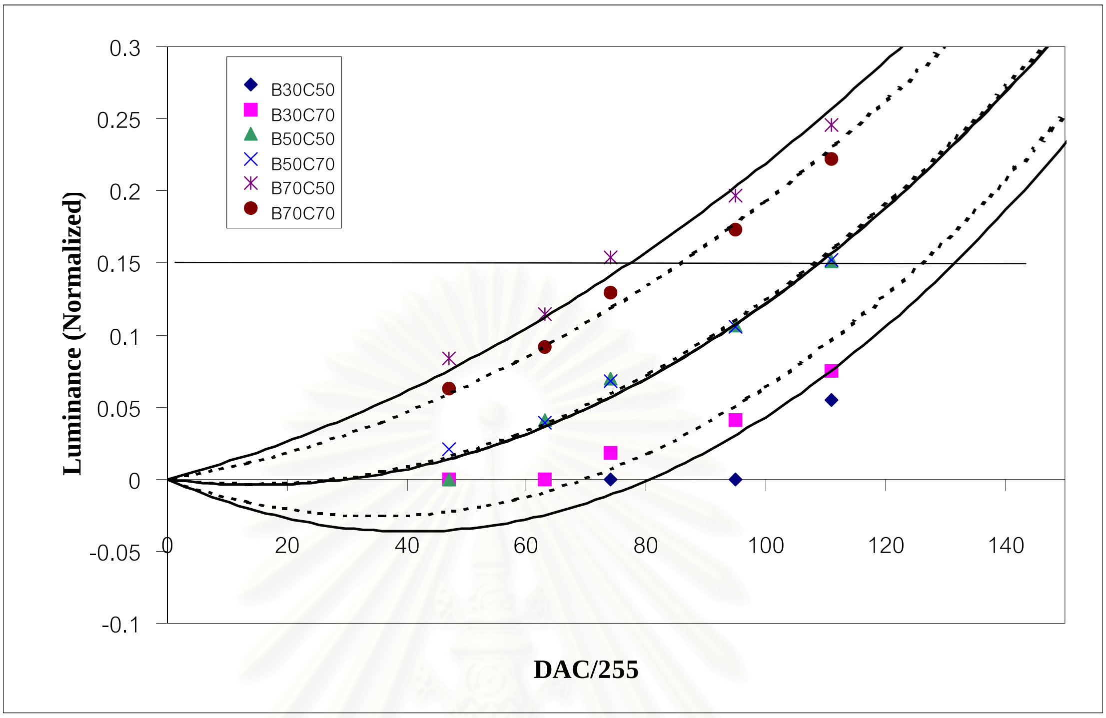


Figure 4-1 The normalized luminance of 5 neutrals measure at 3 different levels of brightness in combination with the contrast of 50 and 70 for LG550D monitor.

From Figure 4-1, the DAC counts that yield constant luminance of 0.15 can be obtained using a second – order polynomial fitting for each curve. The plots of the DAC count against the brightness level for two levels of contrast are shown in Figure 4-2. Because the curvature of each line is very large, the second-order polynomial fittings with three data are achieved successfully as shown in Figure 4-2. With the two fitting functions, the optimum brightness level was calculated at 51 %. At that optimum brightness level, the level of contrast was determined to 95 %, in which the luminance of peak white is just below saturation.

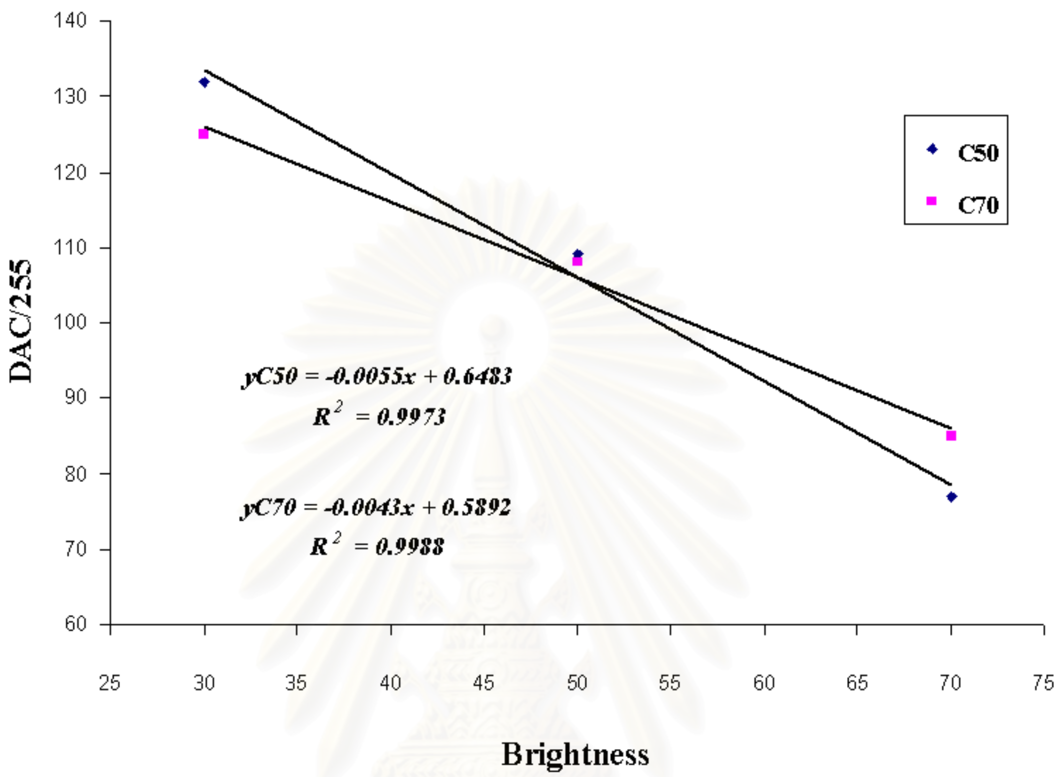


Figure 4-2 DAC count that yields constant luminance vs. brightness level for 2 different contrasts for LG 550D monitor.

From the method are described above, the optimum of brightness level and contrast level are derived. At that point the CRT display is having the stable primaries, in which offset for RGB channels are approximately zero.

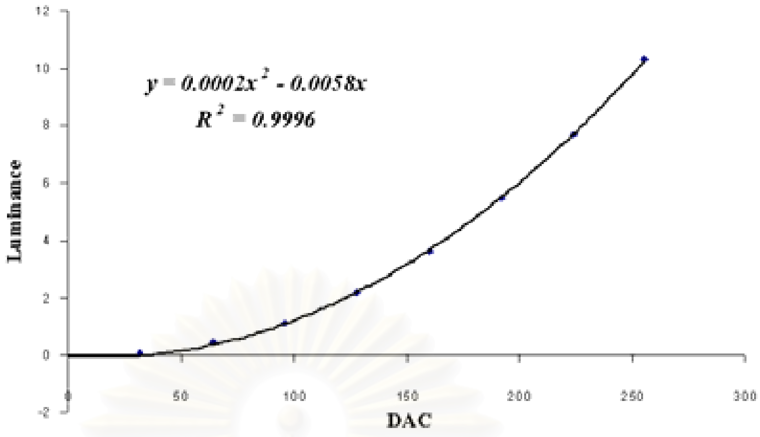
4.1.2 *The Gamma of CRT monitor*

According to the monitor set-up, the optimum brightness level and contrast level were applied to the LG 550D monitor. In face that the colorimetry of computer controlled CRT display. It consists of two stages: a non-linear stage, where DAC values are converted to the scalar, and a linear stage, where the scalar are transformed to the CIE tristimulus value. The measurement of colorimetry for three primaries is required for calculating the relation of computer controlled CRT and tristiulus value.

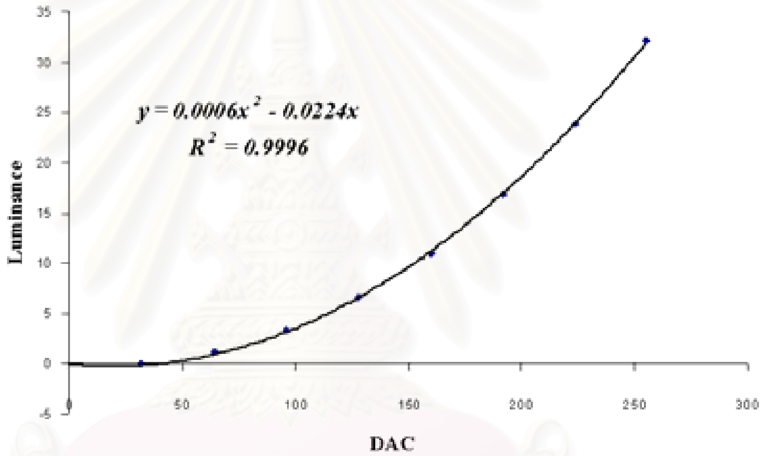
For the nonlinear stage, measurement of tone reproduction for three channels is done. The results are shown in Table 4-3 and the tone reproduction curves of primaries are shown in Figure 4-3; (a) red channel, (b) green channel and (c) blue channel.

Table 4-3 Measurement of tone reproduction of three primaries of CRT by using PR650 Spectrophotometer.

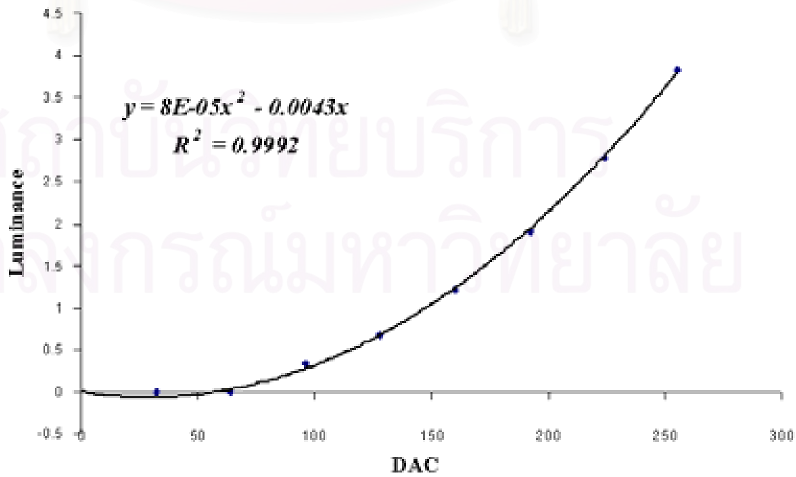
DAC	RED (cd/m^2)	GREEN (cd/m^2)	BLUE (cd/m^2)
0	0.00	0.00	0.00
32	0.11	0.00	0.00
64	0.45	1.27	0.00
96	1.12	3.36	0.33
128	2.18	6.58	0.68
160	3.62	11.00	1.22
192	5.46	16.80	1.91
224	7.70	23.80	2.79
255	10.30	32.20	3.83



(a)



(b)



(c)

Figure 4-3 The tone reproduction of three primary channels (a) red channel, (b) green channel and (c) blue channel

The scalar value R, G and B are normalization of luminance for each channel. These normalized values are used to estimate the parameter for nonlinear transforming from DAC to RGB. An accelerated non-linearity, gamma (γ), is an intrinsic property of the particular CRT and setting video LUT. The gamma was obtained by applying the linear least-squares optimization method to determine. All three channels have the identical nonlinear relationship between the digital count and the scalar value. The Eq.(2-1) was used as the linear optimization. The normalization of the scalar values were plotted against the normalized luminance for each channel as shown in Figure 4-4 for channel red, green, and blue are present in (a), (b) and (c) respectively. The parameters were calculated as shown in Table 4-4.

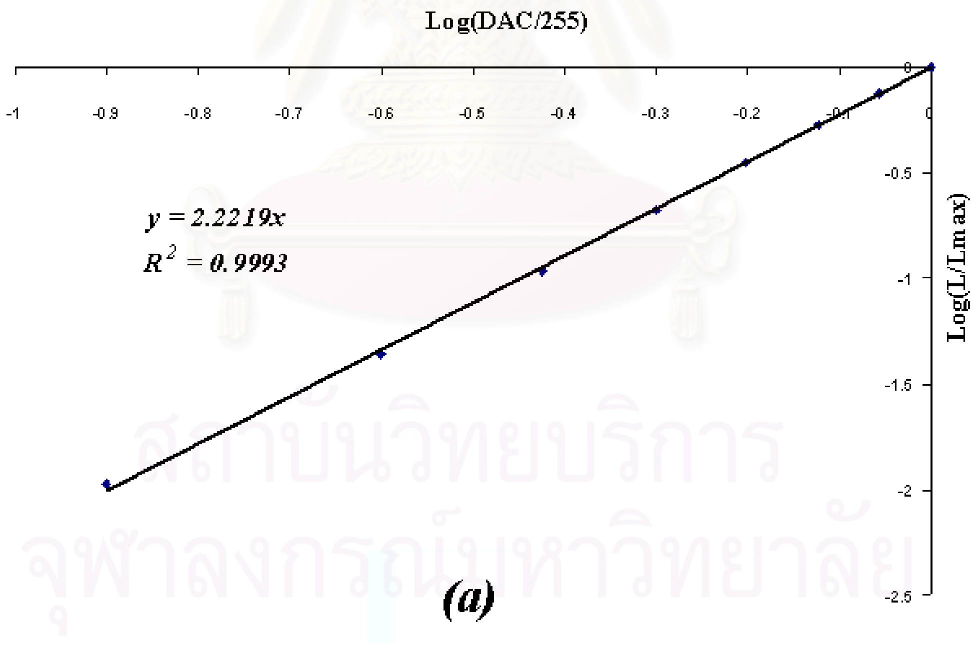
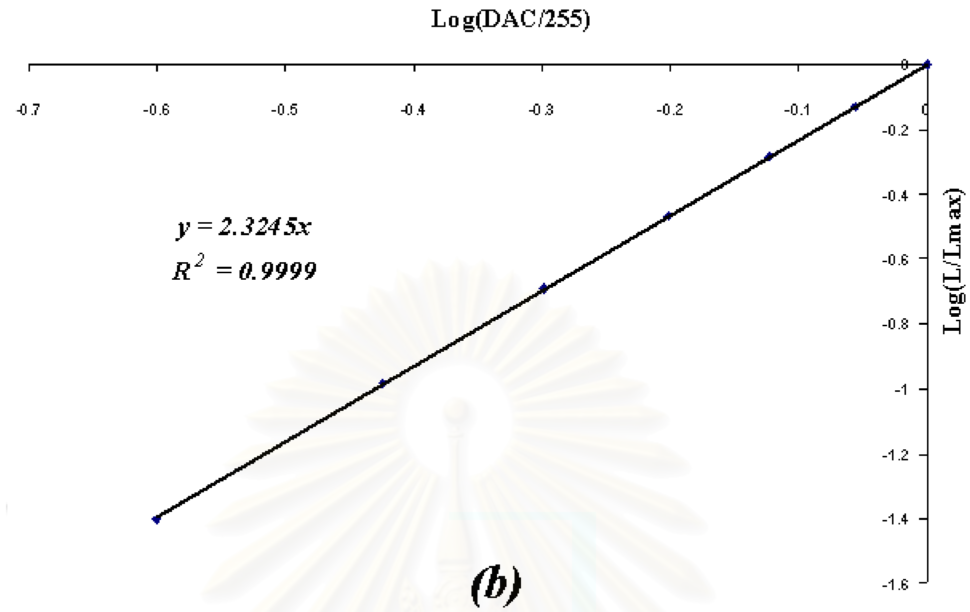


Figure 4-4 The linear optimization of logarithm of the normalized luminance against the logarithm of the normalized digital count for three primaries channel: (a) red, (b) green, and (c) blue



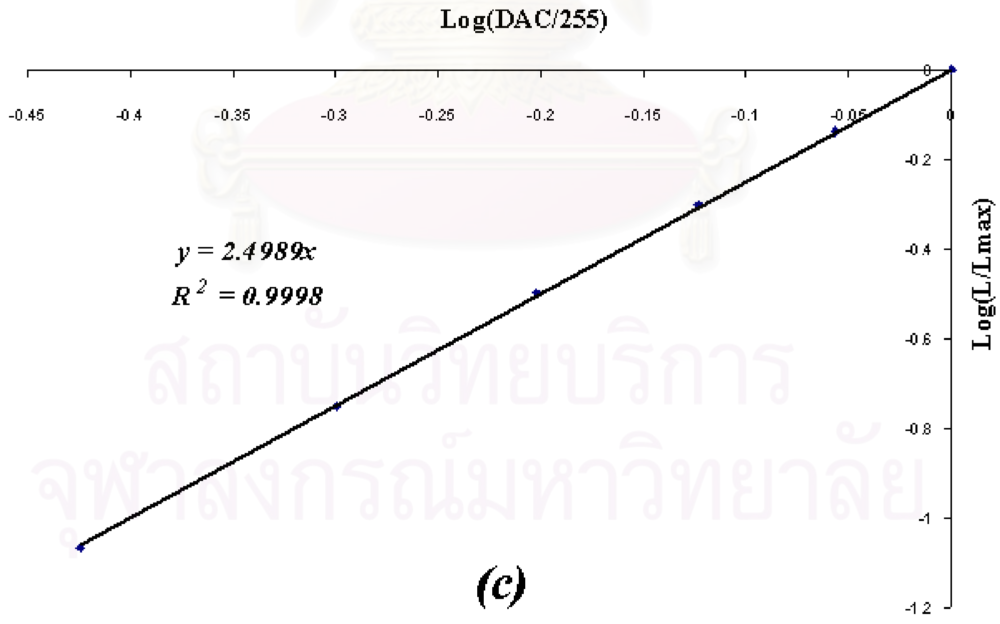


Figure 4-4 The linear optimization of logarithm of the normalized luminance against the logarithm of the normalized digital count for three primaries channel: (a) red, (b) green, and (c) blue (continued)

Table 4-4 The parameter for non-linear transform from DAC to RGB code value

Channel	L_{max} (cd/m^2)	Gamma (γ)	Gain Amplifier (k_g)	Biased Offset (k_o)
RED	10.30	2.2219	1.0019	0.0037
GREEN	32.20	2.3245	1.0006	0.0008
BLUE	3.83	2.2868	1.0041	0.0013
		Average	1.0022	0.0019

From the parameter, the equations for digital count of each channel were obtained,

$$d_{red} = 255\left(\frac{R^{1/2.22} + 0.0037}{1.0019}\right)$$

$$d_{green} = 255\left(\frac{G^{1/2.33} + 0.0008}{1.0006}\right) \qquad \text{…Eq (4-1)}$$

$$d_{blue} = 255\left(\frac{B^{1/2.50} + 0.0013}{1.0041}\right)$$

The scalar R, G, and B are luminance ratio, $R = \frac{L_r}{L_{r\,max}}$, $G = \frac{L_g}{L_{g\,max}}$ and $B = \frac{L_b}{L_{b\,max}}$. And d_{red}, d_{green}, and d_{blue} are the RGB code value for display color on CRT monitor.

According to ideal CRT monitor setup, the computer control CRT display should have the normalized gain amplifier equals unity (k_g =1) and the normalized biased offset equals zero(k_o=0). The result from the measured showed that, after setting the brightness level at 51 % and the contrast level at 95 %, the average gain amplifier equals 1.0022 and the average biased offset equals 0.0019. The result implied that the setup brightness and contrast level were correct, and the display from the LG 550D having stable primaries. When CRT displays have stable in three primaries the result of display can be predict by the non-linear equation of the primaries converted to the scalar, as in Eq.(4-1).

4.1.3 *The Matrix Transformation of Tristimulus value*

For the linear stage, the scalar transformed to the CIE tristimulus of CRT monitor was used. The chromaticity coordinate of three primaries was measured and the results are shown in Table 4-5. The measuremwnt were made by the spectrophotometer of SpectraScan PR650 for each channel at 255 level with the other two channels set at 0 level. The coordinate of monitor white point was also shown in this Table.

Table 4-5 The CIE chromticity coordinate of primary color and white point of LG 550D monitor

Color	x	y	u'	v'	X	Y	Z
RED	0.625	0.333	0.435	0.522	19.33	10.30	1.30
GREEN	0.283	0.600	0.117	0.560	15.19	32.20	6.28
BLUE	0.150	0.070	0.170	0.177	8.21	3.83	42.68
WHITE	0.307	0.333	0.193	0.470	39.76	43.10	45.80

From the CIE chromaticity coordinate of red, green and blue, the matrix transfrom from XYZ tristimulus to RGB scalar value was obtained:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 19.33 & 15.19 & 8.21 \\ 10.30 & 32.20 & 3.83 \\ 1.30 & 6.28 & 42.68 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \qquad \ldots Eq.(4\text{-}2)$$

and from the inverse transformation of the matrix. The luminance of each channel was calculated by rearrange the inverse matrix:

$$\begin{bmatrix} L_r \\ L_g \\ L_b \end{bmatrix} = \begin{bmatrix} 0.7064 & -0.3121 & -0.1078 \\ -0.7108 & 1.3319 & 0.0172 \\ 0.0044 & -0.0198 & 0.0907 \end{bmatrix} \begin{bmatrix} \frac{x}{y} L \\ L \\ \frac{(1-x-y)}{y} L \end{bmatrix} \qquad \ldots Eq.(4\text{-}3)$$

The two stage equations for the colorimetry of computer controlled the CRT display were found. The non-linear transformation of the DAC value to the scalar value was determine by Eq.(4-1), and the linear transform of the scalar to the CIE tristimulus value was determined by Eq.(4-3).

According to the experiment the 47 test stimuli selected by chosen the u'v' coordinates. Those were then converted to RGB code value by using Eq.(4.1) and the matrix in Eq.(4-3). It was displayed on the LG 550D CRT color monitor as the test stimuli for detecting the border and the brightness experiment.

4.2 The Recognized Visual Space of Illumination

According to the concept of the Recognized Visual Space of Illumination (RVSI)[2,3], the border of RVSI is considered as an upper limit of the test stimuli luminance and also a transition point of appearance color from object color mode to light source color mode. A test stimulus displayed on a CRT monitor appeared like a color patch with a higher lightness. To obtain the border of RVSI, the subject can adjust the color stimuli on the CRT to find the transition point. By gradually decreasing the CRT luminance, the color on the CRT began to appear with low luminance. The test stimuli look like an object place in the room.

To detect the border luminance of each stimulus on the CRT monitor comparing with human's sight, six observers were used as sample. Each observer detected the 47 color stimuli in the 5 lux and 50 lux illumination conditions.

The results from experiment are shown in Figure 4-5 as an example, the result obtained from the subject NJ for 47 stimuli. The results at the observer’s room illuminate 5 lux and 50 lux are shown in Figure 4-5(a) and (b), respectively. Along the horizontal axis is the test stimulus number is taken according to Table 3-1 and along the ordinate the border is taken in the luminance (cd m^{-2}). Each point is the average of ten determinations and the vertical lines are the standard deviations. The border luminance means the upper limit of stimuli luminance, that the subject perceived a natural appearance. The test stimuli still appeared like an object place in the room. When the luminance of stimuli was higher than the border, the appearance mode was changed. The subject perceived an unnatural appearance on the test stimuli compared to an object in the room. The stimuli appeared like a light color emitted from the source. These curves showed that the border is changed individually depending on the test color.

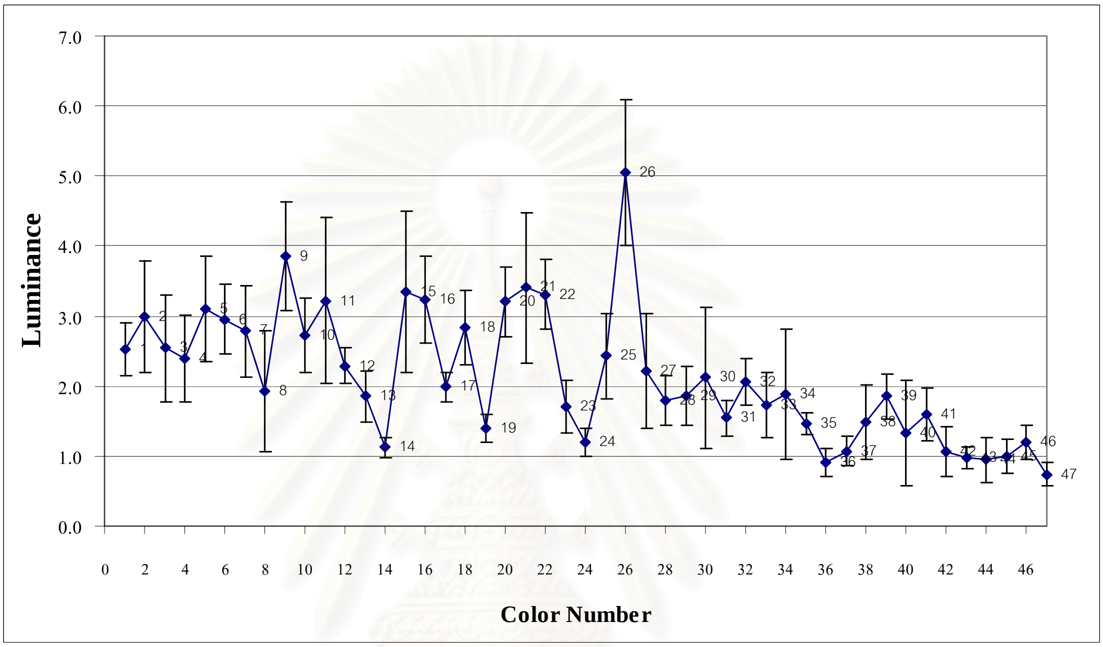


Figure 4-5 (a) The border of RVSI by subject NJ at 5 lux observer's room

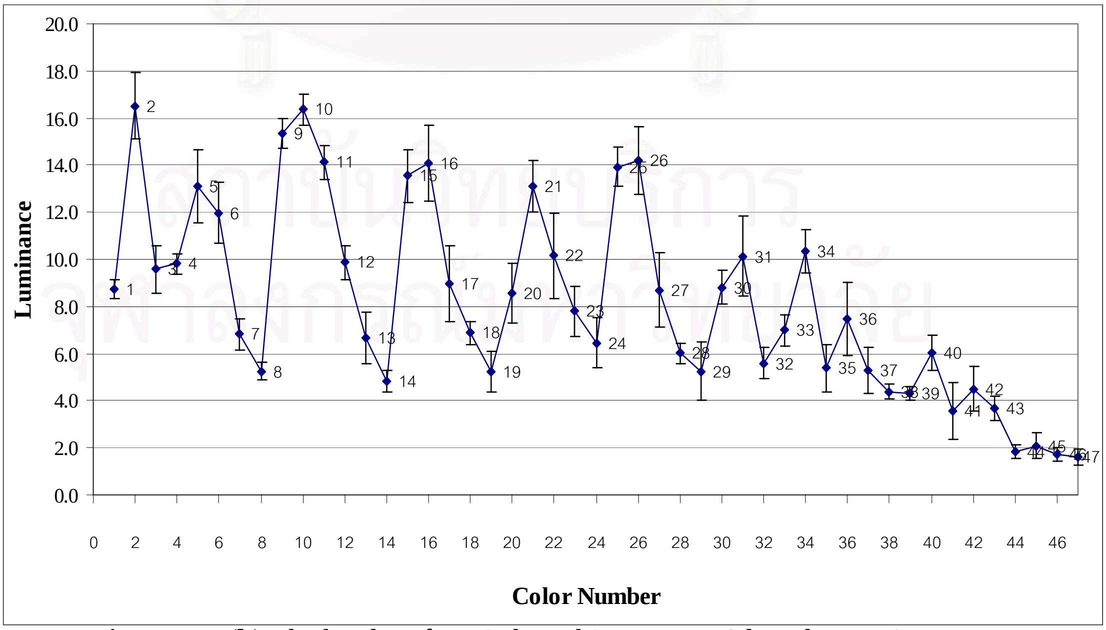


Figure 4-5 (b) The border of RVSI by subject NJ at 50 lux observer's room.

The border luminance differs among subjects. The curves of 47 test stimuli have been plotted for all 6 subjects, as shown in Figure 4-6. The data were showed in Appendix C. The result of NJ is also included. The results from each subject are shown (a) KJ, (b) NJ, (c) PP, (d) PS, (e) WU and (f) YT. Different symbols correspond to observer's room illuminate. The open circles and filled circles were 5 lux and 50 lux respectively.

Table 4-6 Average of standard deviation of ten determinations for the border luminance

Subject	Standard deviation of *Border at 5 lux*	Standard deviation of *Border at 50 lux*	Subject	Standard deviation of *Border at 5 lux*	Standard deviation of *Border at 50 lux*
KJ	0.7828	1.1288	PS	0.2032	1.1328
NJ	0.5142	0.9073	WU	0.4921	1.1283
PP	1.0333	1.4831	YT	0.1104	0.6344

All of 6 subjects showed that the border of 50 lux condition is higher than 5 lux condition, in the other hand, when the room's illuminant was 50 lux, the luminance of CRT was made high for the border of RVSI. From the results, the smaller standard deviation for 5 lux compared to 50 lux was shown in Table 4-6. It means the border was easier in dark room because the colorfulness of the object in the room was lower as compared to the room of 50 lux and the determination of border was not bothered by surrounding color.

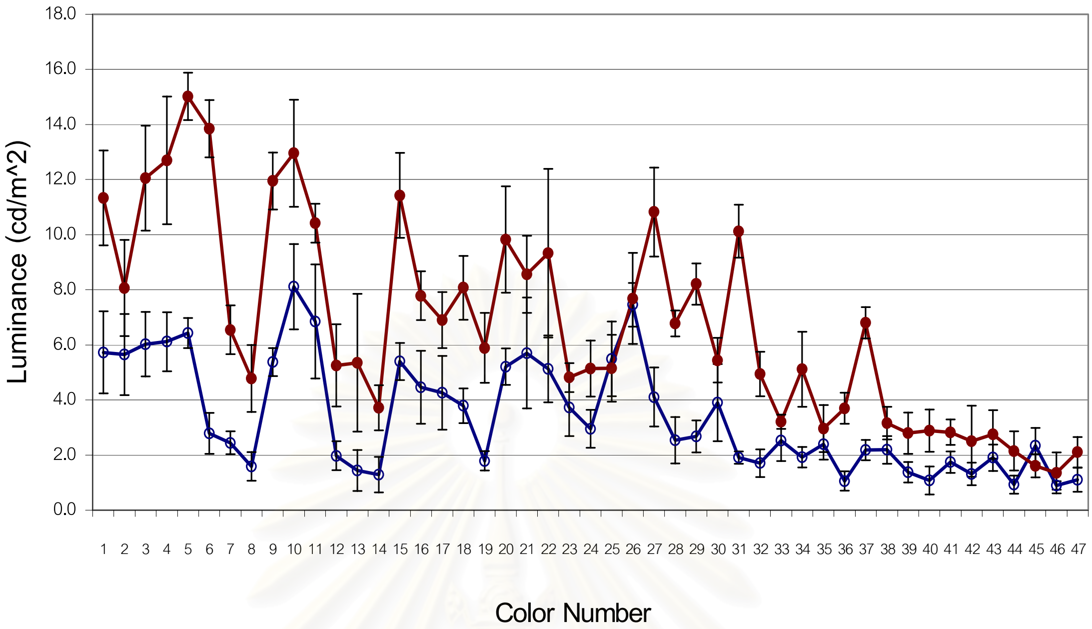


Figure 4-6 (a) The border of RVSI by subject KJ

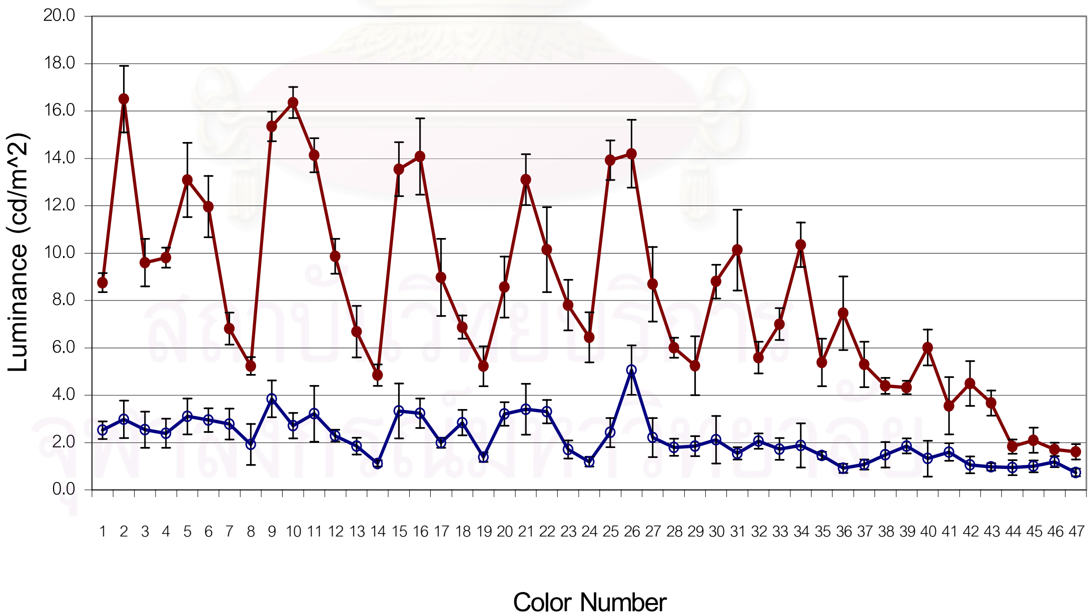


Figure 4-6 (b) The border of RVSI by subject NJ

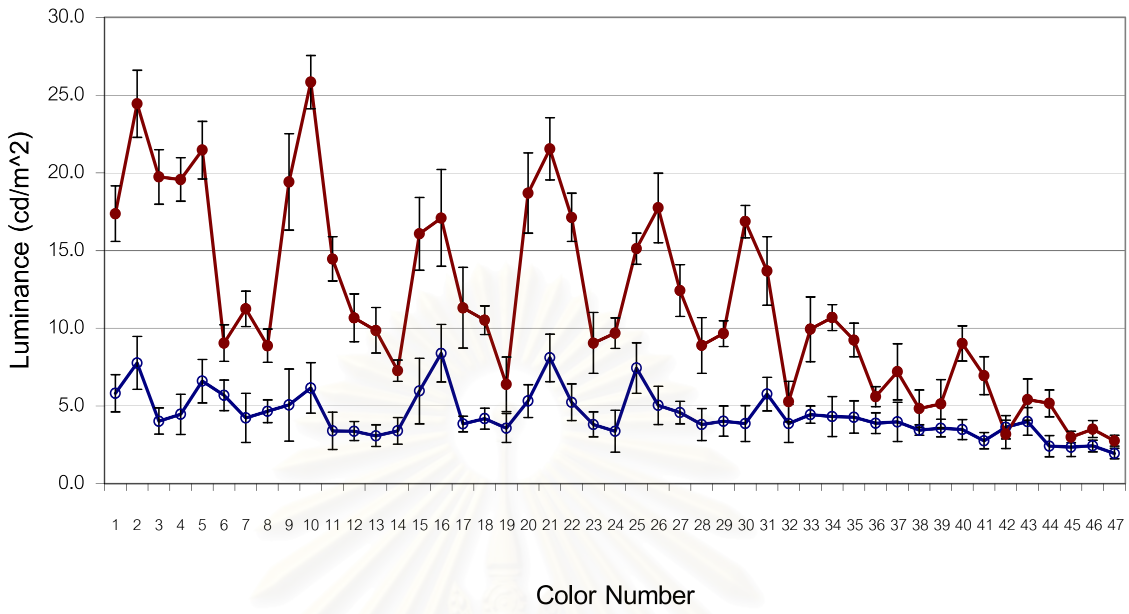


Figure 4-6 (c) The border of RVSI by subject PP

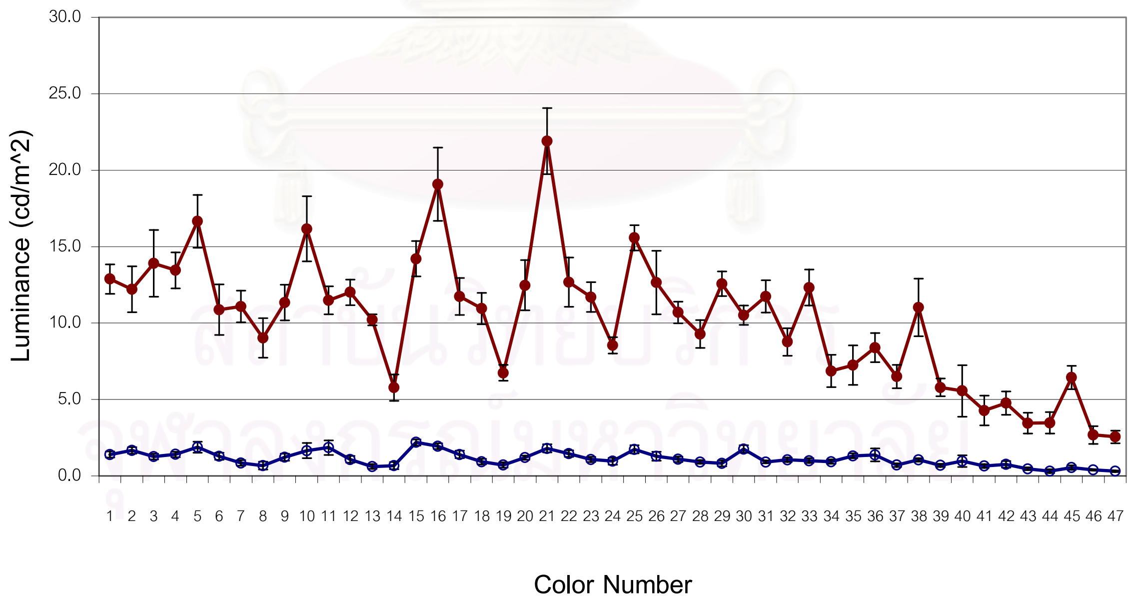


Figure 4-6 (d) The border of RVSI by subject PS

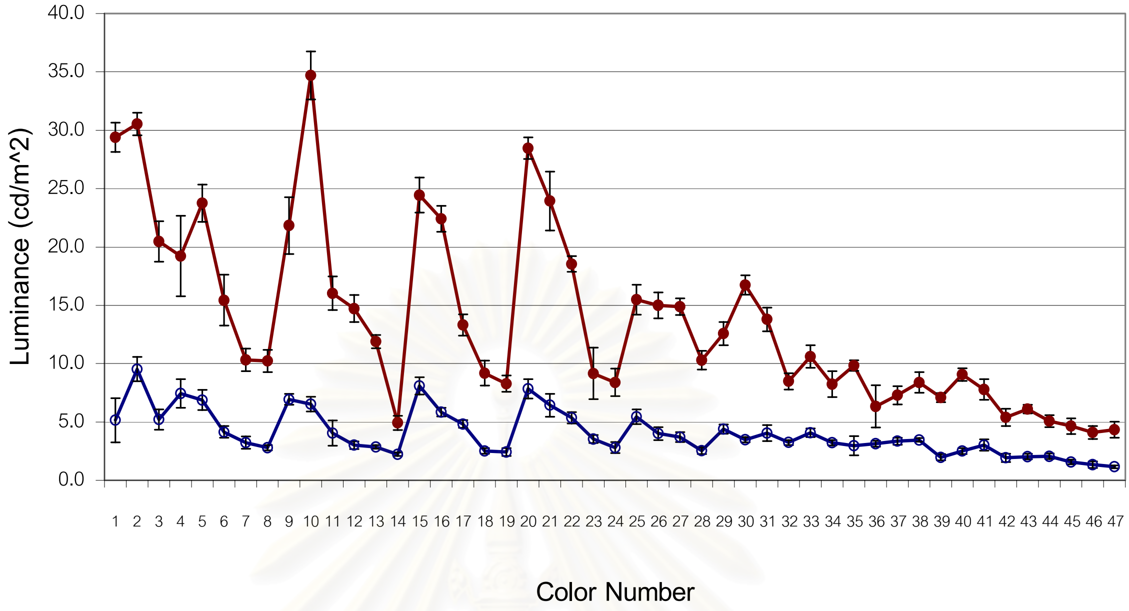


Figure 4-6 (e) The border of RVSI by subject WU

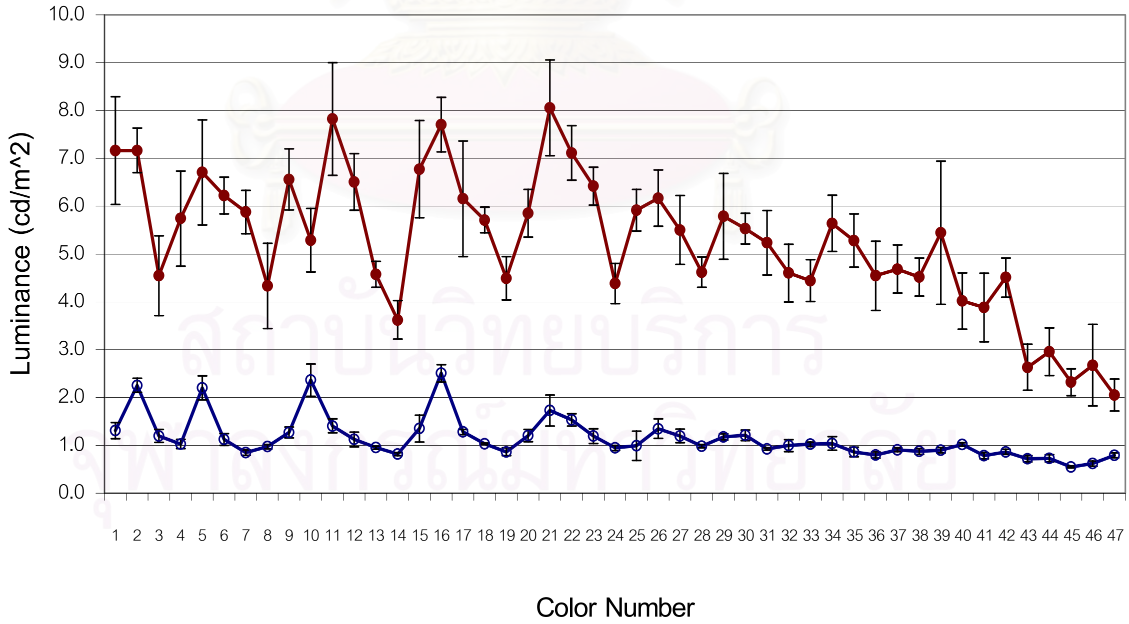


Figure 4-6 (f) The border of RVSI by subject YT

The shape of both conditions is similar for all subjects. Most of subjects showed a peak of curve at the stimuli around number 5, 10, 16, 21 and 26. The curve was droped around number 8, 14, 19 and 24, and at the stimuli number 32 to 47 the border luminance was low as shown in Figure 4-6.

These results are compared in Figure 4-7 and Figure 4-8 by grouping them with respect to the illuminant of observer's room. Figure 4-7 is for 5 lux condition and Figure 4-8 is for 50 lux condition. The results from six subjects have been plotted together. Variations among subjects are found. The results have an individual differences depend on each subject. According to the curves, it has two differences among subject, one is the difference in the magnitude of border luminance and the other is the difference in shape of the curves. The border is very high for most of color stimuli in subject WU for both room's illuminant conditions and the border is so low for the subject YT, although the shape of they curves appeared similar to other subjects.

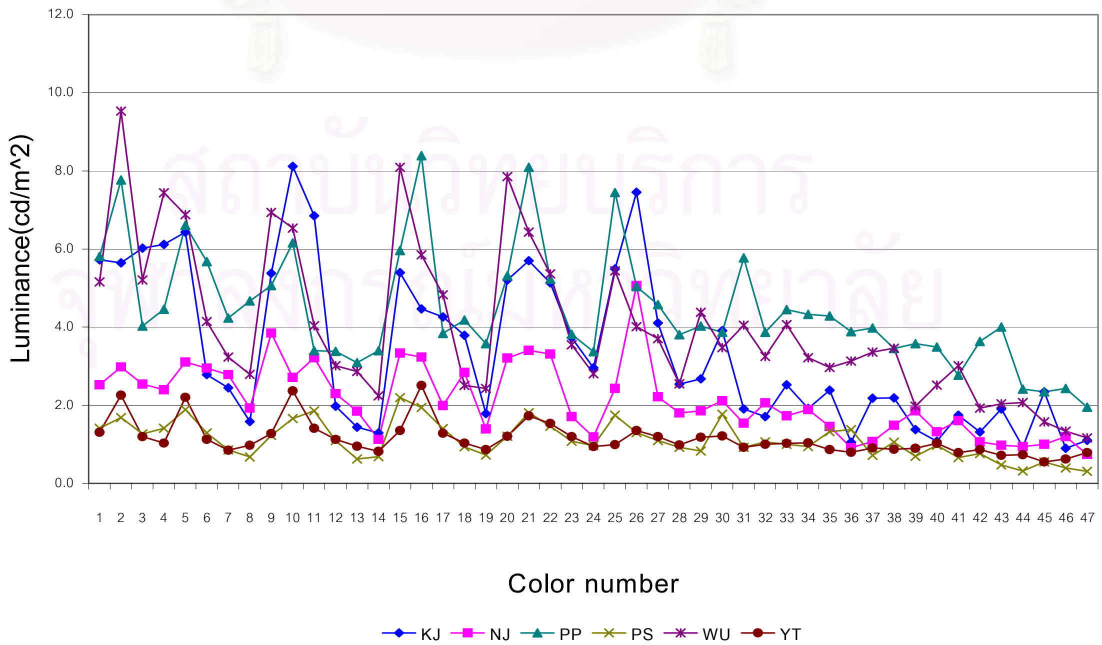


Figure 4-7 the border of RVSI for all subjects at 5 lux illumination condition.

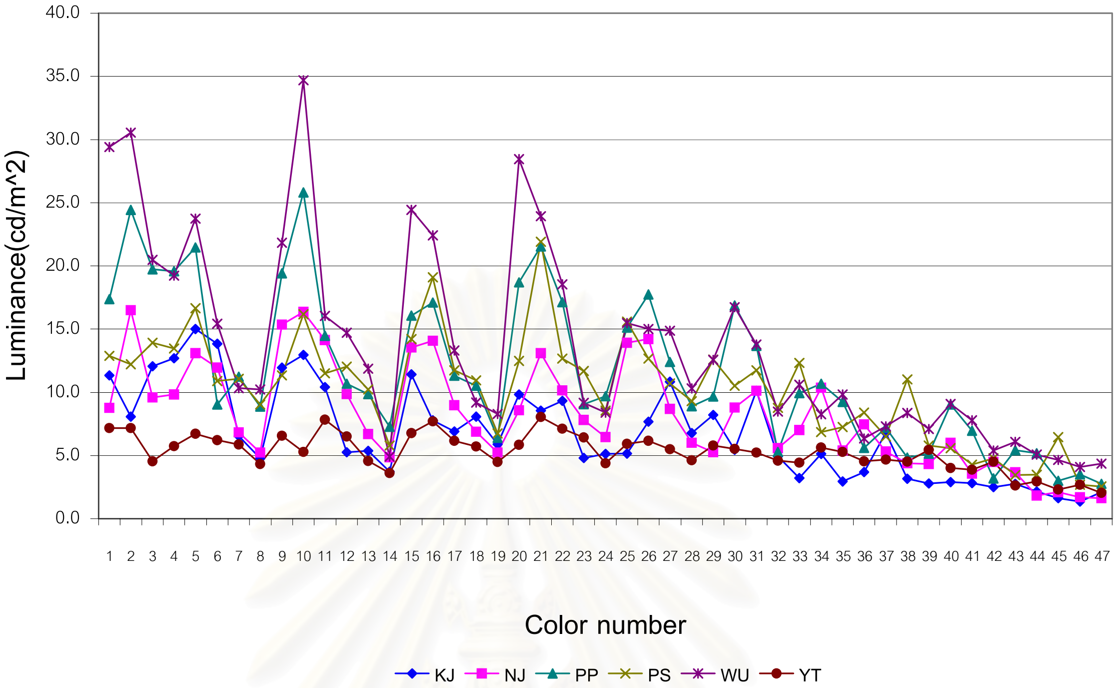


Figure 4-8 the border of RVSI for all subjects at 50 lux illumination condition

Try to interpret the results by normalized all curves in vertical direction as follows. Firstly the average of all data points was calculated for each subject. Then from the average of this data it was possible to calculate total average. Finally each curve was shifted vertically so that the average of each coincided with total the average. The equation for normalized is follow:

$$\text{Normalized Luminance} = \frac{\text{Border Luminance}}{\text{Total Average of Border Luminance}} \quad \text{...Eq. (4-4)}$$

The results are shown in Figure 4-9 for 5 lux condition and Figure 4-10 for 50 lux condition. In the Figure showed that the shape of the curves for all subjects are similar, in the other hand, the perception of the subjects were same in most of color stimuli and bit difference in some color.

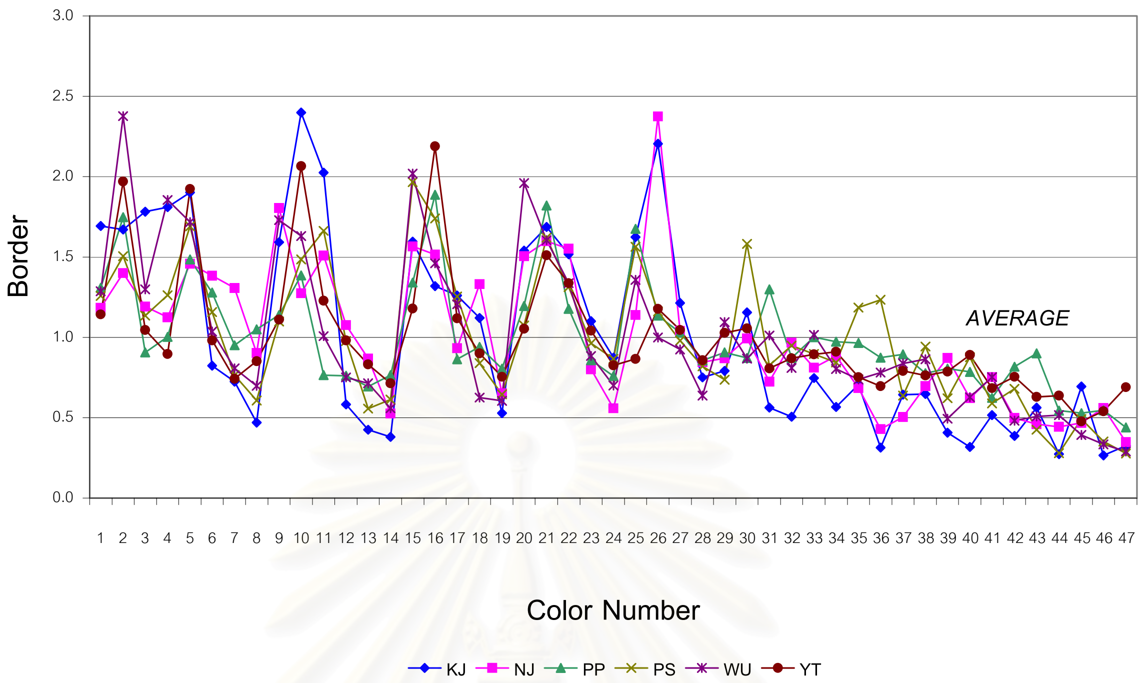


Figure 4-9 the border of RVSI was shifted vertically by the average of each subject coincided with total average for 5 lux illumination condition.

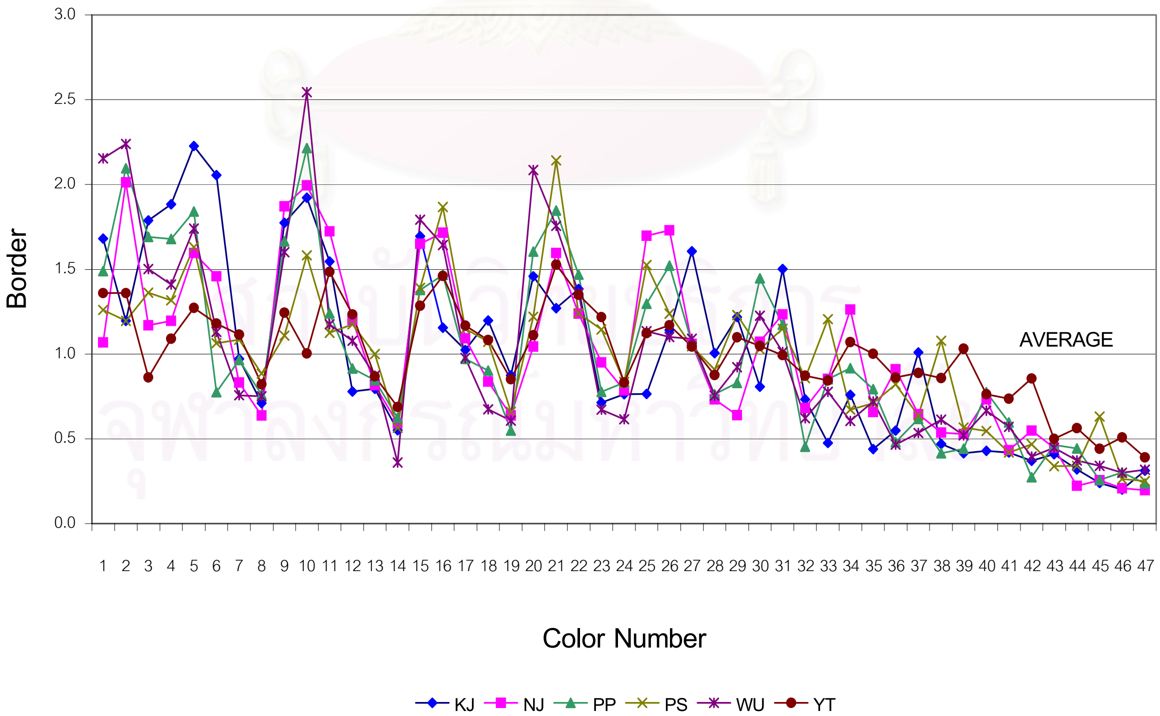


Figure 4-10 the border of RVSI was shifted vertically by the average of each subject coincided with total average for 50 lux illumination condition.

The tendency of all subject curves was considered by took the average and find standard deviation of all subjects. The results showed in Figure 4-11 and their data in Table 4-7. In Figure 4-11, the open circles are representing the results of the average border at 5 lux and the filled circles are represent 50 lux condition. The standard deviations are show in vertical line for each point. The magnitudes of border luminance are found different. The border of 50 lux is higher than 5 lux. The standard deviation is small for 5 lux condition compare to 50 lux condition. The reason is the illuminant was low so that the border was easy to adjust. Considering in curves of the average result, by the normalization method applying to the average border luminance data, their result was shown in Figure 4-12. The results showed that for both conditions the curve shape were similar and had same tendency, the peak and the curve shape drop at the same stimulus number.

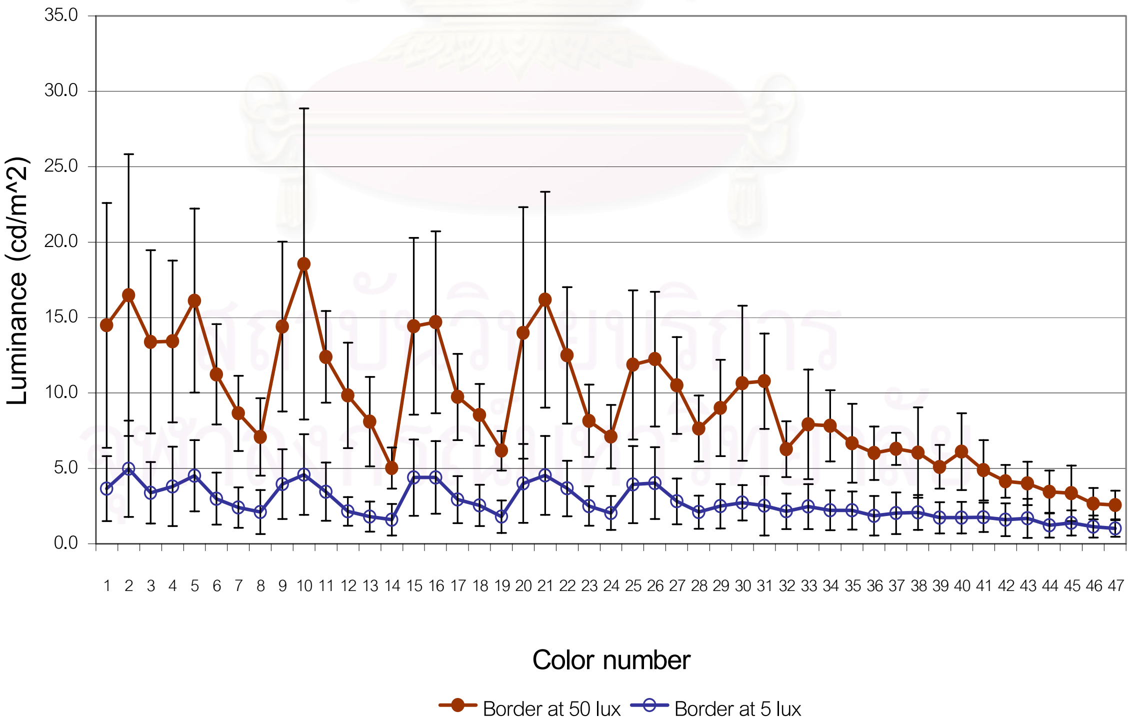


Figure 4-11 Average of the border of RVSI and their standard deviation of variation determined from all 6 subjects for 5 lux and 50 lux.

Table 4-7 the average data of the border of RVSI from all subjects and their standard deviation.

Color number	u'	v'	Border at 5 lux		Border at 50 lux	
			Luminance (cd/m^2)	*Standard Deviation*	*Luminance (cd/m^2)*	*Standard Deviation*
1	0.150	0.550	3.656	2.148	14.483	8.118
2	0.200	0.550	4.978	3.200	16.489	9.347
3	0.125	0.525	3.377	2.034	13.386	6.083
4	0.175	0.525	3.808	2.623	13.418	5.366
5	0.225	0.525	4.519	2.361	16.113	6.097
6	0.275	0.525	2.996	1.731	11.232	3.320
7	0.325	0.525	2.400	1.340	8.649	2.488
8	0.375	0.525	2.104	1.461	7.080	2.574
9	0.150	0.500	3.953	2.314	14.407	5.623
10	0.200	0.500	4.590	2.672	18.548	10.308
11	0.250	0.500	3.460	1.933	12.396	3.038
12	0.300	0.500	2.145	0.948	9.839	3.502
13	0.350	0.500	1.801	1.002	8.098	2.961
14	0.400	0.500	1.591	1.042	5.027	1.368
15	0.175	0.475	4.389	2.544	14.412	5.855
16	0.225	0.475	4.397	2.408	14.693	6.025
17	0.275	0.475	2.935	1.560	9.734	2.858
18	0.325	0.475	2.548	1.356	8.552	2.055
19	0.375	0.475	1.794	1.074	6.172	1.313
20	0.150	0.450	3.998	2.620	13.980	8.328
21	0.200	0.450	4.529	2.615	16.184	7.146
22	0.250	0.450	3.671	1.844	12.490	4.528
23	0.300	0.450	2.509	1.316	8.159	2.394
24	0.350	0.450	2.040	1.120	7.099	2.104
25	0.175	0.425	3.925	2.560	11.864	4.944
26	0.225	0.425	4.036	2.386	12.241	4.461
27	0.275	0.425	2.816	1.517	10.499	3.199
28	0.325	0.425	2.099	1.100	7.649	2.186
29	0.150	0.400	2.490	1.476	9.010	3.195
30	0.200	0.400	2.724	1.171	10.644	5.144
31	0.250	0.400	2.519	1.966	10.784	3.162
32	0.300	0.400	2.157	1.174	6.277	1.851
33	0.175	0.375	2.466	1.502	7.919	3.627
34	0.225	0.375	2.220	1.314	7.818	2.358
35	0.275	0.375	2.212	1.271	6.659	2.618

Table 4-7 the average data of the border of RVSI from all subjects and their standard deviation. (Contented)

Color number	u'	v'	***Border at 5 lux***		***Border at 50 lux***	
			Luminance (cd/m^2)	*Standard Deviation*	*Luminance (cd/m^2)*	*Standard Deviation*
36	0.150	0.350	1.861	1.314	6.007	1.765
37	0.200	0.350	2.034	1.378	6.297	1.067
38	0.250	0.350	2.085	1.155	6.050	3.002
39	0.175	0.325	1.730	1.036	5.098	1.446
40	0.225	0.325	1.732	1.037	6.100	2.546
41	0.275	0.325	1.761	0.978	4.879	2.004
42	0.200	0.300	1.592	1.082	4.141	1.081
43	0.250	0.300	1.686	1.300	4.001	1.428
44	0.175	0.275	1.233	0.822	3.442	1.423
45	0.225	0.275	1.392	0.829	3.351	1.843
46	0.200	0.250	1.144	0.721	2.672	1.041
47	0.175	0.225	1.010	0.553	2.572	0.958
			Average	*1.594*	*Average*	*3.599*

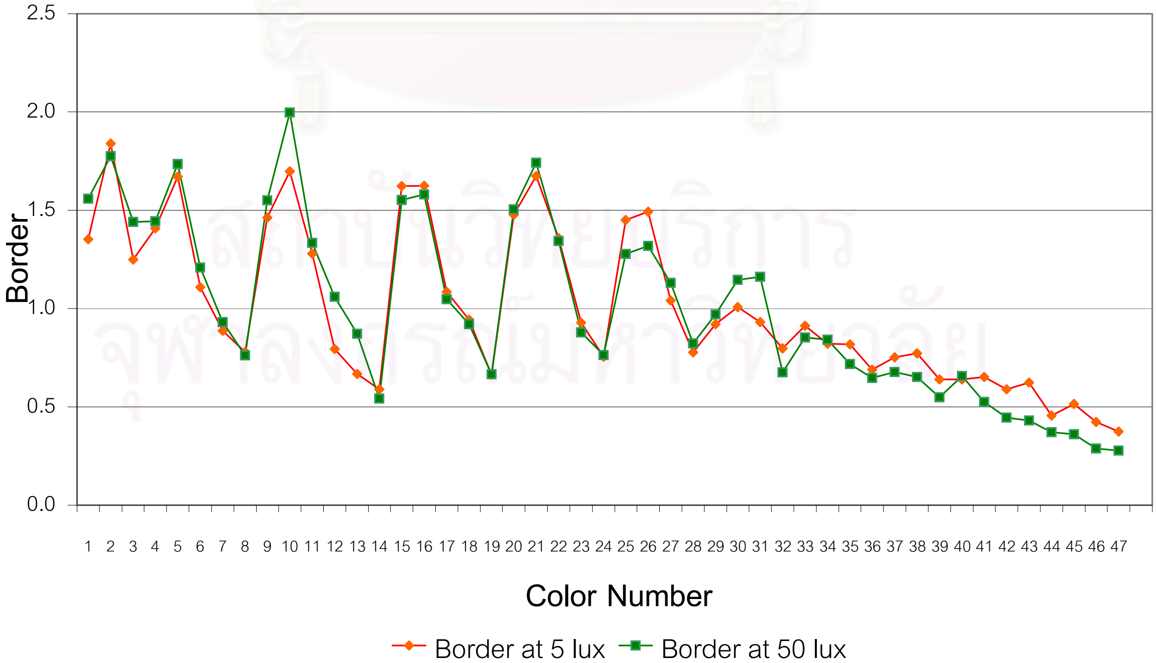


Figure 4-12 The normalized of the average border luminance

From the result found that the highest of border luminance was located at the stimulus number 10 for both conditions. The stimulus number 10 represented the display of chromaticity of (u’ = 0.200, v’ = 0.500), this point was near that of the observer’s room illumination (207, 489). The result implies that the border luminance is high for the stimulus, which have chromaticity near that of the room.

For confirm the relation between the result at 5 lux condition and 50 lux condition. Plotted of the border luminance at 5 lux and 50 lux was made. The result shown in Figure 4-13, the horizontal axis is represented the border luminance at 5 lux and the vertical axis is represented the border luminance at 50 lux. The linear relation are found as an equation,

$$(BD)_{50lx} = 3.7429(BD)_{5lx} - 0.8329 \qquad \text{...Eq.(4-5)}$$

The correlation coefficient (R^2) is 0.9335 .It is note here that this relation can predict the border luminance of any color stimuli.

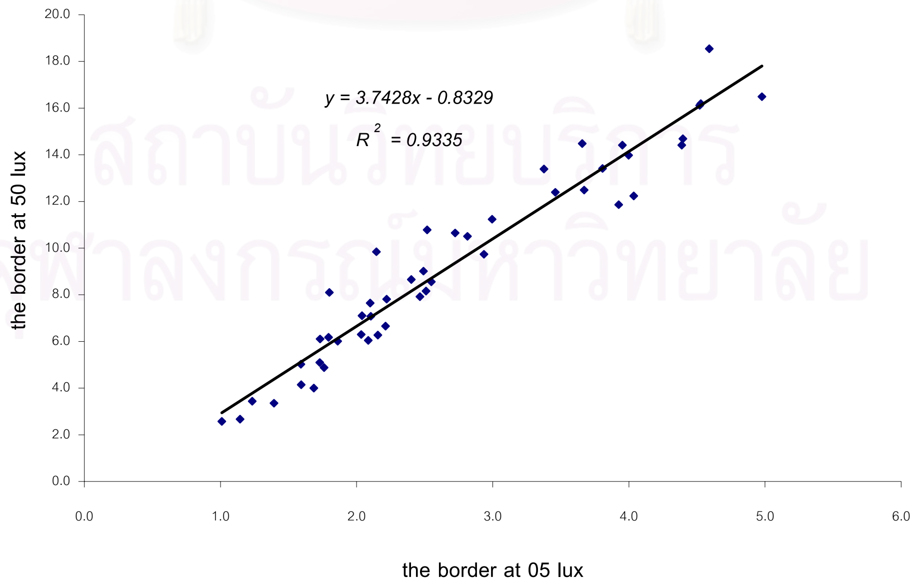


Figure 4-13 the relation between the border at 5 lux and 50 lux is found in linear relation.

According to the average result (Table 4-7), the surface plots of these data are shown in Figure 4 - 14 for 5 lux condition and Figure 4-15 for 50 lux. And also from the average data, the contour plots of the border are shown in Figure 4-16 for 5 lux and Figure 4-17 for 50 lux.

The surface shown that at the 50 lux condition the border luminance was higher than at the 5 lux, but the surface shapes were same for both conditions. At color number 2, 5, 10, 15, 16, 21, 25 and 26 are found high in the border, these region are represent neutral and green color. In Figure 4-16 and Figure 4-17 were show the chromaticity coordinate of Fluorescent lamp, that used in the observer room. The color stimuli, which have the chromaticity coordinate near the source coordinate, will have high in the border luminance. The color stimuli number 15, 16, 21 as sample

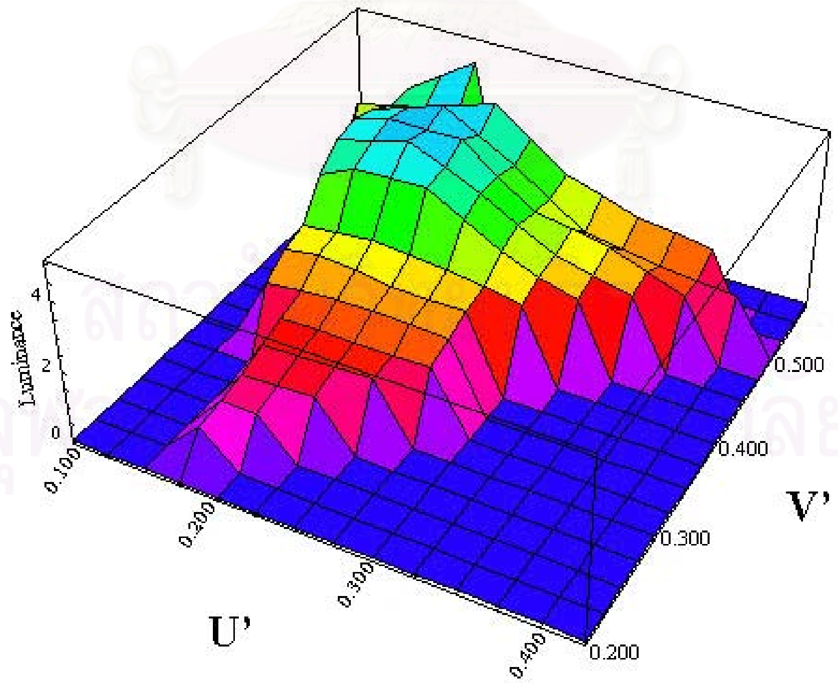


Figure 4-14 The surface plot of the average border luminance at 5 lux

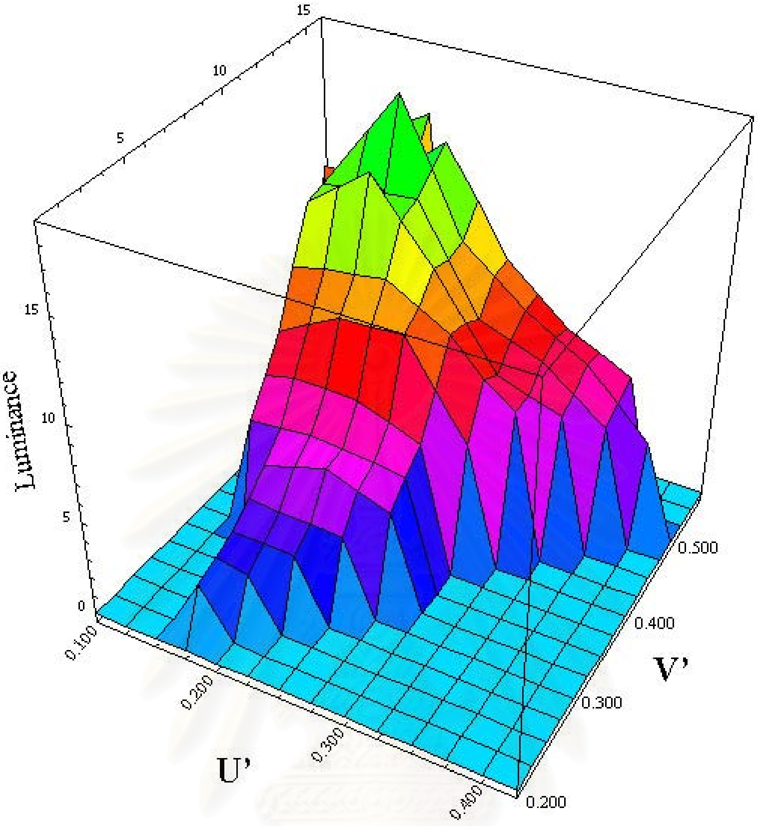


Figure 4-15 The surface plot of the average border luminance at 50 lux

At color number 8, 14, 19, 24 and 28 are found low in the border luminance, these region are represent red color. And the color stimuli number 32 to 47 are found also low in the border, these are regions of blue color. Moreover, the stimuli which have low in the border they would also have a small standard deviation. The large standard deviations were found in the stimuli, which have high in the border luminance. The result mentioned above should be referred to the CIE Lu'v' UCS diagram, which shown in Figure 4-16 for 5 lux and Figure 4-17 for 50 lux.

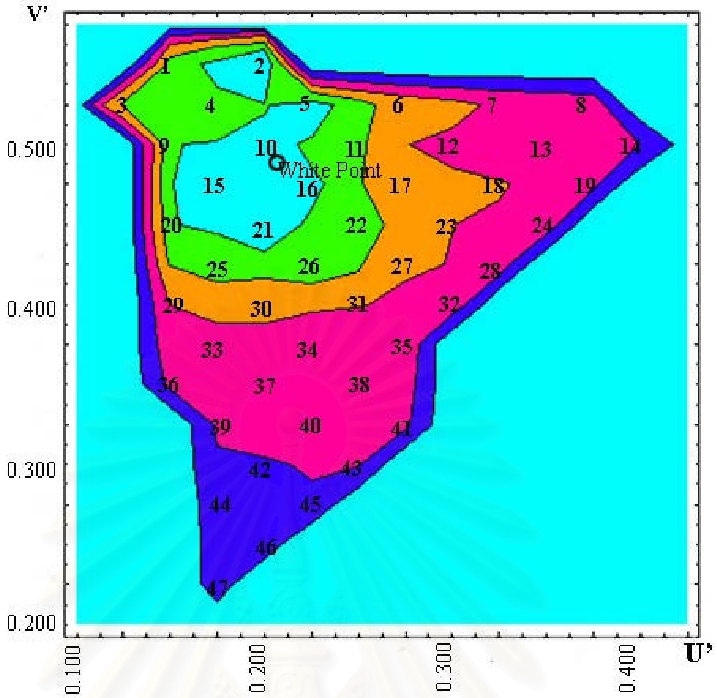


Figure 4-16 The contour lines of the average border luminance at 5 lux , plotted on u'v' diagram.

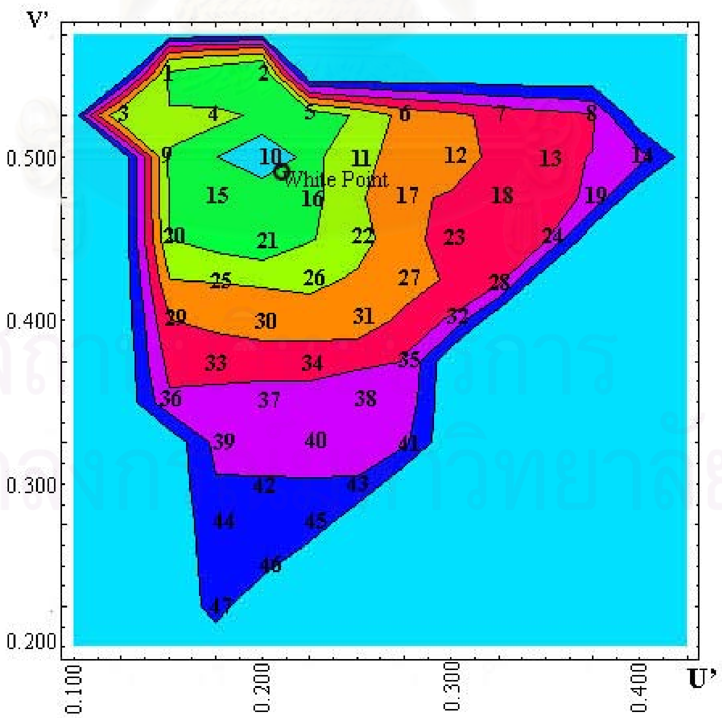


Figure 4-17 The contour lines of the average border luminance at 50 lux, plotted on u'v' diagram.

4.3 The Brightness Matching

The brightness of the test stimulus determined the mode perception, and brightness matching of the test stimulus work as a determining factor. These suggested by some literature [23,24]. In this experiment investigate the brightness of CRT test stimuli, by hypothesis that “the border of RVSI is determined by brightness of test stimuli”, the brightness matching was used in order to investigate this hypothesis.

The heterochromatic brightness matching of the test stimuli was done for a white reference of N7 Munsell color chart. That is the brightness matching between a color test stimuli displayed by CRT monitor and an achromatic reference chart of N7. The subjects were adjusted the test stimulus until the test stimulus was perceived to be of equal brightness to the reference stimulus. The subjects repeated to adjust ten times for every color stimulus. The brightness of test stimuli was observed by five subjects for 47 colors stimuli (the set of test stimuli is the same as the border experiment) under 2 illuminance level condition, 5 lux and 50 lux.

The data from all five subjects are shown in Figure 4-18 and the data are shown in Appendix D. The different 5 subjects are (a) KJ, (b) NJ, (c) PP, (d) PS, and (e) WU. In Figure, the open symbols are represented the result from 5 lux iluuminance condition and the filled symbols are 50 lux. Each point represent the average of ten determinations and vertical line shows the standard deviation.

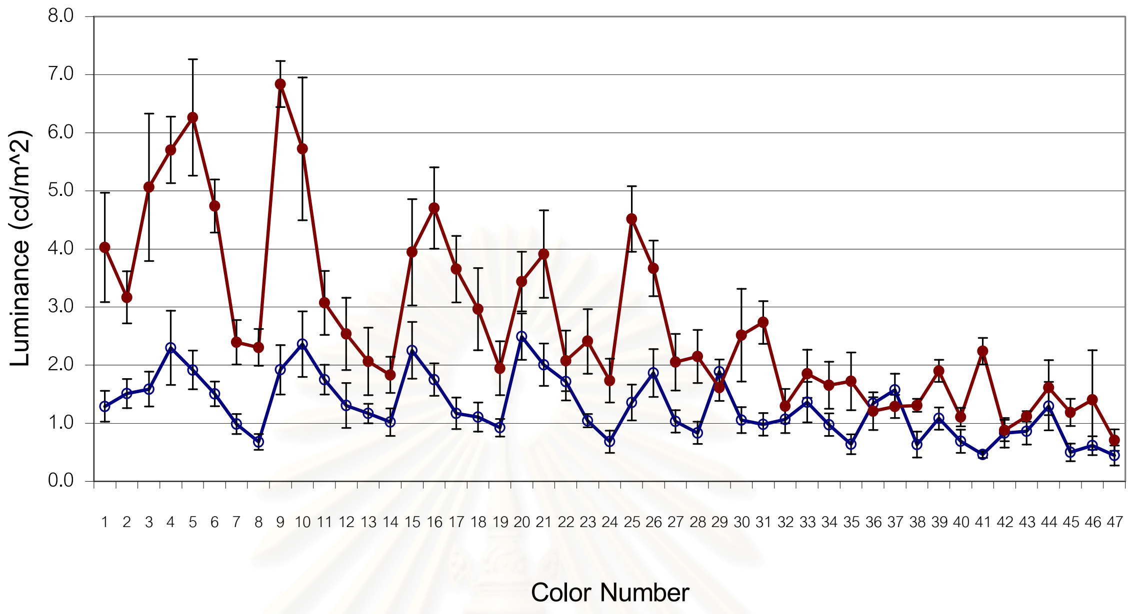


Figure 4-18 (a) The matched luminance by subject KJ

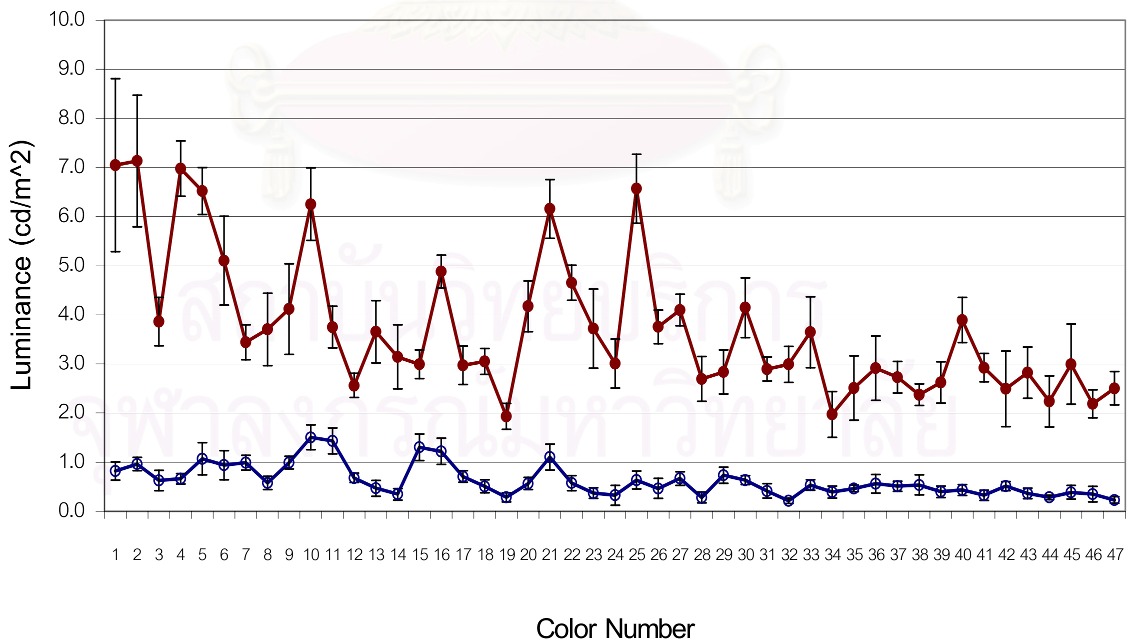


Figure 4-18 (b) The matched luminance by subject NJ

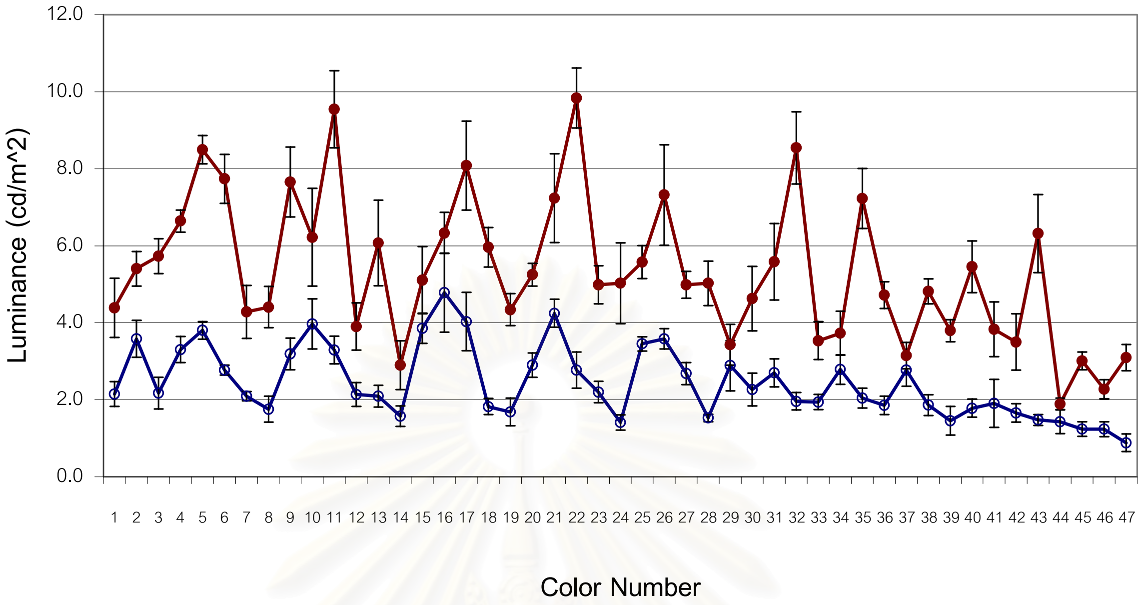


Figure 4-18 (c) The matched luminance by subject PP

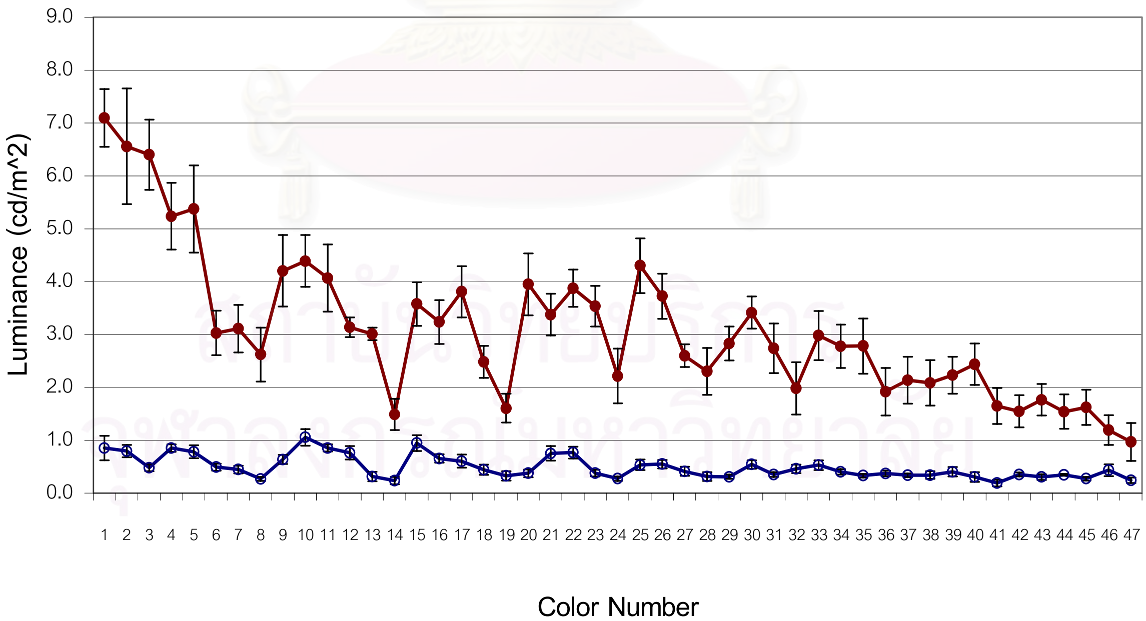


Figure 4-18 (d) The matched luminance by subject PS

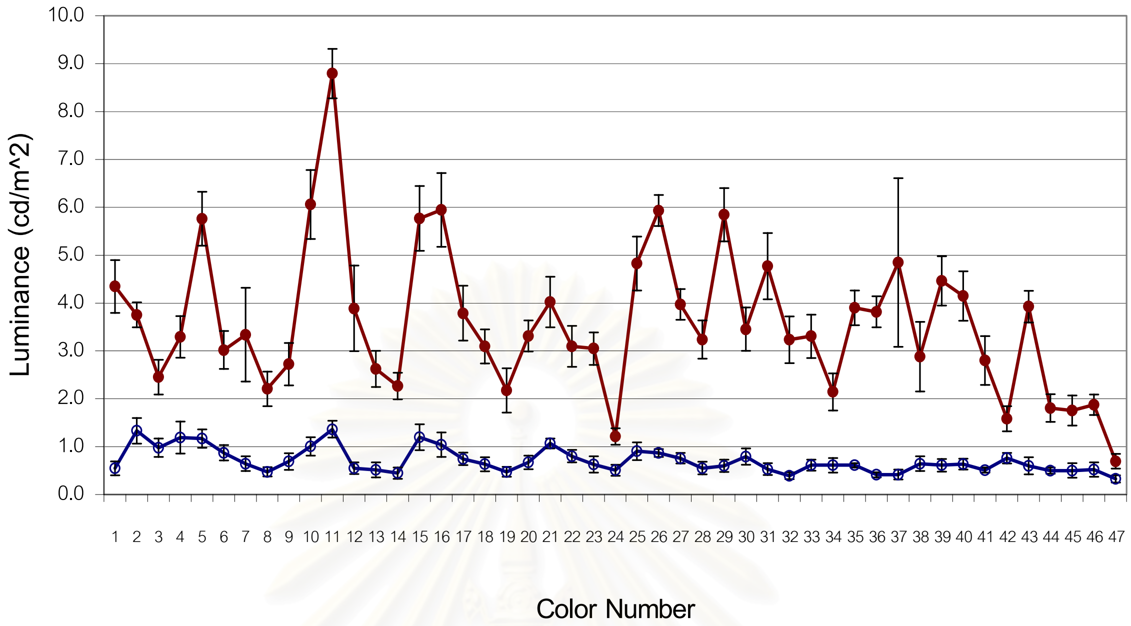


Figure 4-18 (e) The matched luminance by subject WU

The matched luminance differs among subjects and changes for difference test stimuli as it as in the case of the border experiment. When compared in case of 5 lux and 50 lux the curves are same tendency, they found high and low in the matched luminance at the same test stimulus. At the 50 lux was found higher in the matched luminance compare to 5 lux. The standard deviation of 50 lux condition larger than 5 lux condition. This situation implies that it was easier for subjects in general to do the heterochromatic brightness matching in darker room.

The result from the five subjects was plotted together in Figure 4-19 for 5 lux condition and Figure 4-20 for 50 lux condition. The variations among subjects are found. By the similar method as the border experiment, normalized of all the curves in vertical direction was done.

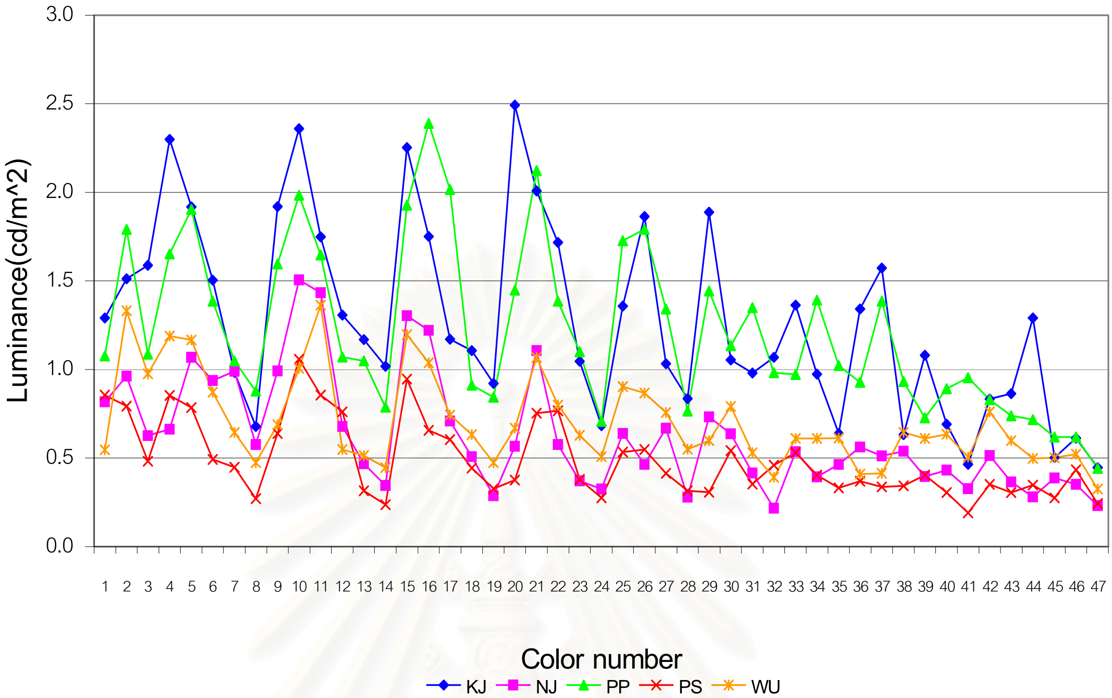


Figure 4-19 The matched luminance of all subjects at 5 lux illumination condition

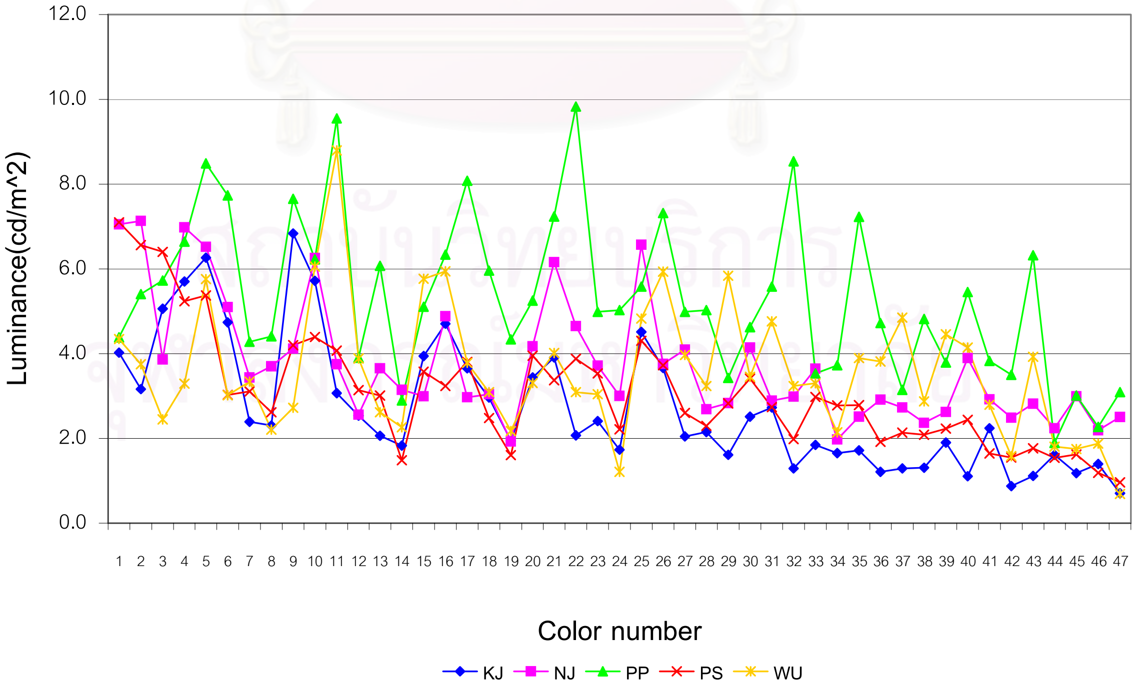


Figure 4-20 The matched luminance of all subjects at 50 lux illumination condition.

The normalized plot are shown in Figure 4-21 (5 lux) and Figure 4-22 (50 lux). The similar shape of all curves was found. From the curves they showed the peak of the matched luminance was found in the same test stimulus for different subject. At the test stimuli number 2, 5, 10, 15, 21 and 25 are found high in the matched luminance and found low at the test stimuli number 8, 14, 19, 24 and 28 in each subject. The result implies that the perceptions of all subjects for the heterochromatic matching in the test stimuli are similar.

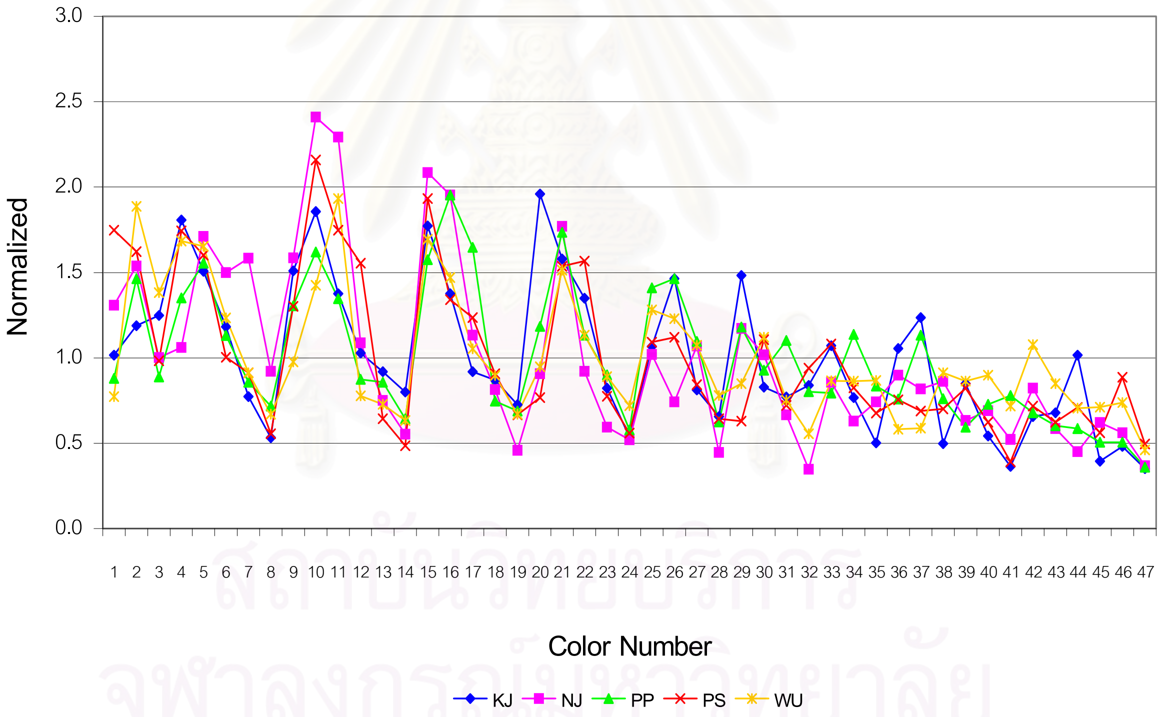


Figure 4-21 The normalization of the matched luminance curves of all subjects at 5 lux illumination condition.

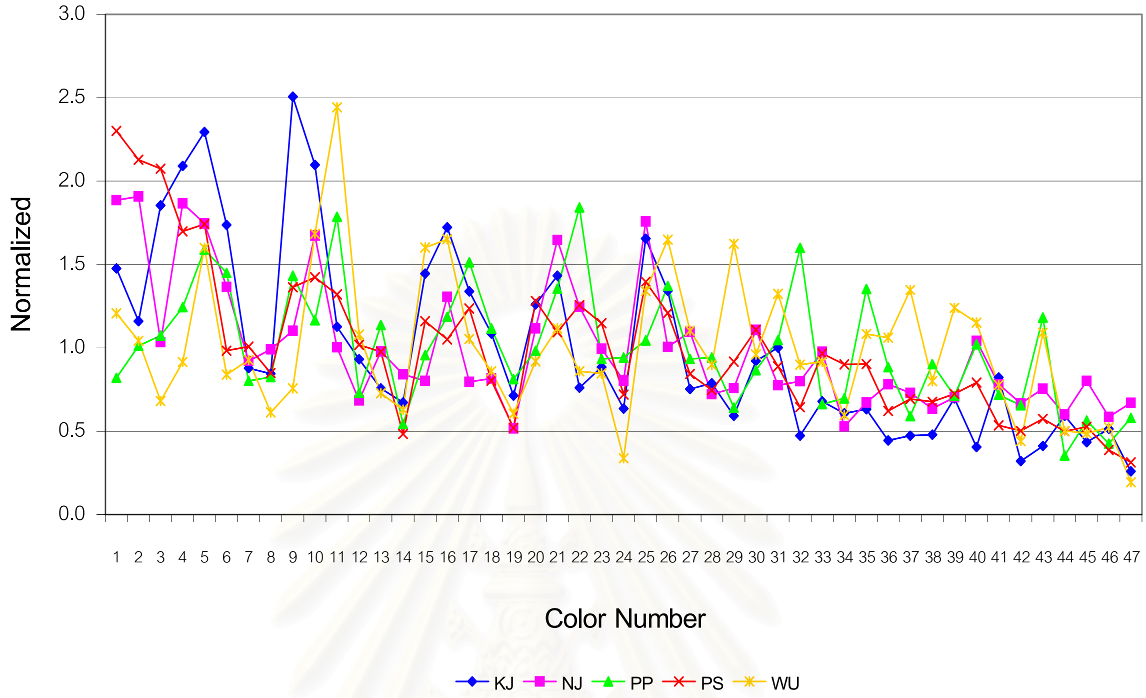


Figure 4-22 The normalization of the matched luminance curves of all subjects at 50 lux illumination condition.

Consider the mean data of all subjects, the average and the standard deviation of all data were calculated. The results are plotted in Figure 4-23, the open symbols correspond to the data from 5 lux condition and the filled correspond to the 50 lux, and their data in Table 4-8. The magnitude of matched luminance are found different, the matched luminance of 50 lux was higher than 5 lux. The standard deviation was small for 5 lux condition compare to 50 lux condition. The reason is, it easy to determine the brightness matching in dark room, there has less of surrounding color to bother the observer.

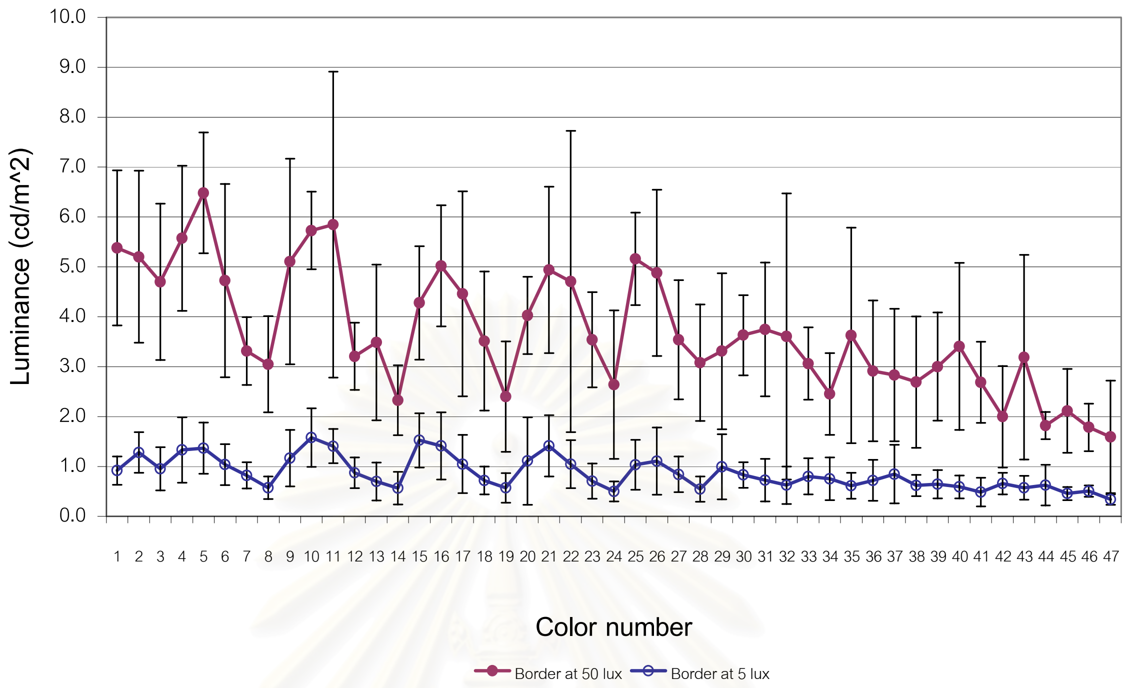


Figure 4-23 The average of the matched luminance and their standard deviation of variation determined from all subjects at 5 lux (open symbols) and 50 lux (filled symbols).

Table 4-8 the average data of the matched luminance from all subjects and their standard deviation.

Color number	**u'**	**v'**	***Border at 5 lux***		***Border at 50 lux***	
			Luminance (cd/m^2)	*Standard Deviation*	*Luminance (cd/m^2)*	*Standard Deviation*
1	0.150	0.550	0.917	0.281	5.380	1.551
2	0.200	0.550	1.278	0.405	5.202	1.722
3	0.125	0.525	0.951	0.433	4.701	1.568
4	0.175	0.525	1.331	0.658	5.572	1.453
5	0.225	0.525	1.368	0.515	6.482	1.209
6	0.275	0.525	1.038	0.411	4.725	1.937
7	0.325	0.525	0.823	0.263	3.314	0.679
8	0.375	0.525	0.575	0.226	3.050	0.965
9	0.150	0.500	1.167	0.568	5.108	2.059
10	0.200	0.500	1.583	0.587	5.730	0.778
11	0.250	0.500	1.410	0.346	5.846	3.067
12	0.300	0.500	0.873	0.309	3.207	0.674

Table 4-8 the average data of the matched luminance from all subjects and their standard deviation (Continued)

Color number	**u'**	**v'**	**Border at 5 lux**		**Border at 50 lux**	
			Luminance (cd/m^2)	*Standard Deviation*	*Luminance (cd/m^2)*	*Standard Deviation*
13	0.350	0.500	0.703	0.380	3.485	1.559
14	0.400	0.500	0.567	0.325	2.327	0.698
15	0.175	0.475	1.525	0.544	4.278	1.135
16	0.225	0.475	1.412	0.674	5.020	1.212
17	0.275	0.475	1.048	0.583	4.461	2.053
18	0.325	0.475	0.721	0.281	3.510	1.393
19	0.375	0.475	0.570	0.295	2.400	1.104
20	0.150	0.450	1.110	0.874	4.024	0.773
21	0.200	0.450	1.412	0.614	4.940	1.666
22	0.250	0.450	1.049	0.481	4.706	3.021
23	0.300	0.450	0.705	0.352	3.540	0.954
24	0.350	0.450	0.499	0.198	2.639	1.489
25	0.175	0.425	1.032	0.502	5.158	0.925
26	0.225	0.425	1.107	0.675	4.880	1.668
27	0.275	0.425	0.843	0.356	3.541	1.192
28	0.325	0.425	0.549	0.253	3.081	1.165
29	0.150	0.400	0.994	0.651	3.311	1.562
30	0.200	0.400	0.832	0.257	3.631	0.802
31	0.250	0.400	0.726	0.426	3.744	1.340
32	0.300	0.400	0.624	0.378	3.608	2.866
33	0.175	0.375	0.802	0.362	3.063	0.724
34	0.225	0.375	0.755	0.427	2.454	0.821
35	0.275	0.375	0.613	0.260	3.628	2.159
36	0.150	0.350	0.722	0.411	2.916	1.412
37	0.200	0.350	0.844	0.586	2.831	1.326
38	0.250	0.350	0.618	0.213	2.692	1.317
39	0.175	0.325	0.643	0.282	3.002	1.085
40	0.225	0.325	0.590	0.229	3.408	1.673
41	0.275	0.325	0.488	0.288	2.688	0.815
42	0.200	0.300	0.658	0.215	1.999	1.017
43	0.250	0.300	0.574	0.238	3.190	2.048
44	0.175	0.275	0.627	0.407	1.819	0.275
45	0.225	0.275	0.457	0.131	2.113	0.840
46	0.200	0.250	0.507	0.116	1.786	0.477
47	0.175	0.225	0.337	0.104	1.594	1.126
			Average	*0.391*	*Average*	*1.348*

According to the average matched luminance curves, the shape of both condition are look similar. At the test stimuli display green color and neutral (color stimuli number 2, 5, 10, 15, 21 and 25) are found high in the matched luminance, while they found low at the test stimuli display red and blue (number 8, 14, 19, 24 and 28). The both conditions were found same in peak number and drop number as shown in same shape of surface plotted of mean data. Figure 4-24 shown the surface of the matched luminance at 5 lux and Figure 4-25 shown the surface of 50 lux

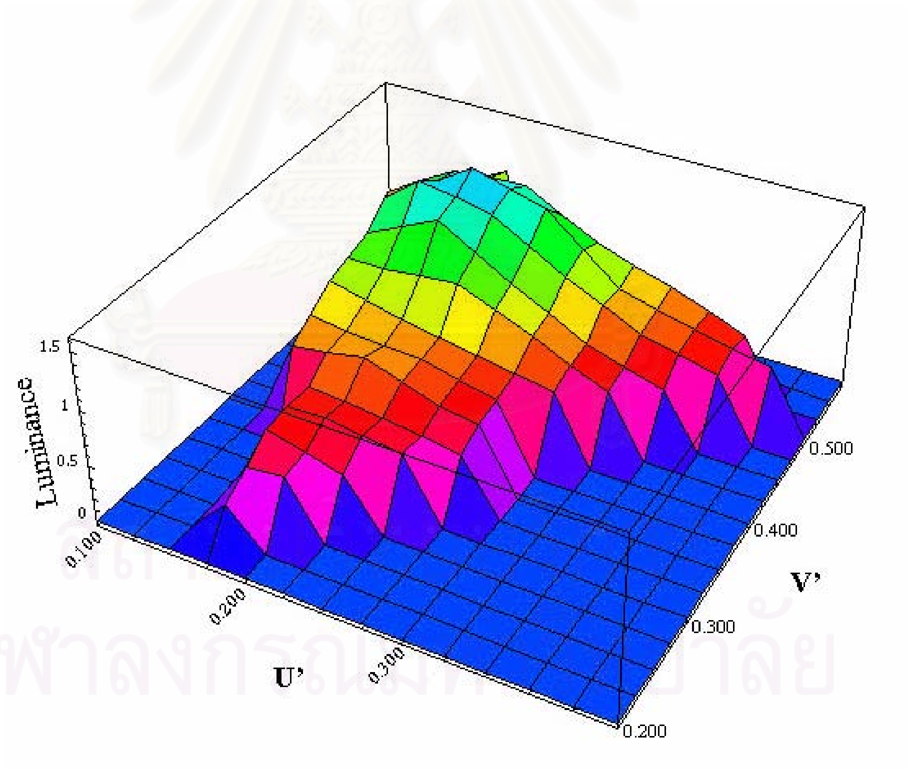


Figure 4-24 The surface plotted of the matched luminance at 5 lux condition.

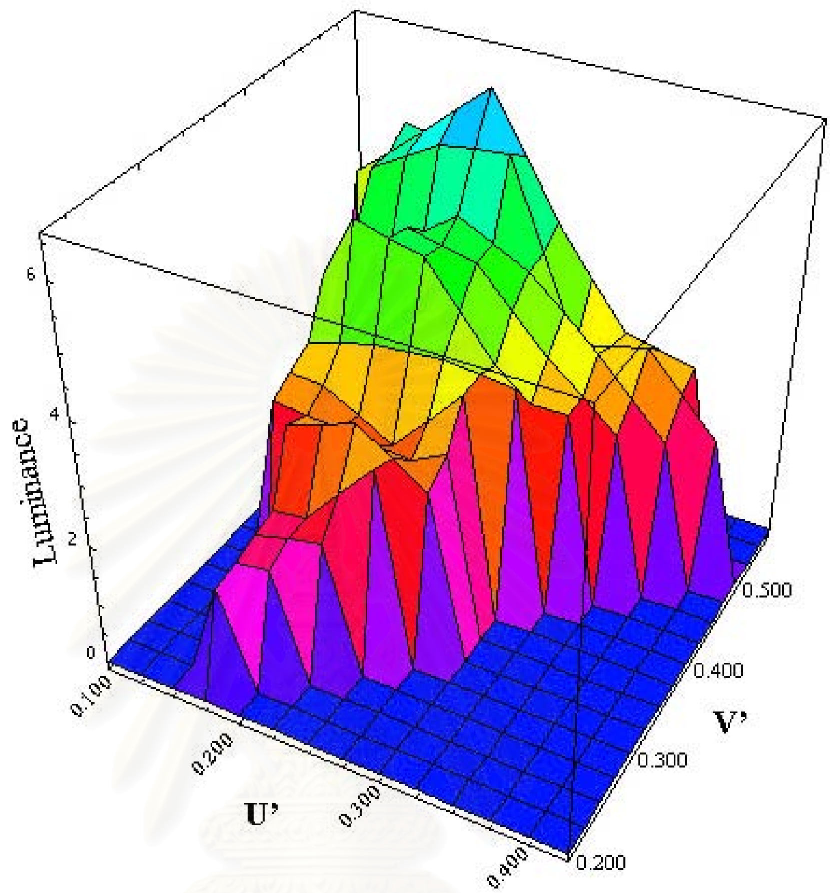


Figure 4-25 The surface plotted of the matched luminance at 50 lux condition.

The contours plotted of the mean result are shown in Figure 4-26 (at 5 lux) and Figure 4-27 (at 50 lux), the plotted referred to the u'v' diagram. The matched luminance are found high at the color which have the chromaticity coordinate near the chromaticity coordinate of the illumination of the observer's room. The color will have low in the matched luminance if these colors are saturation. The matched luminance decrease if the color located in large distance from the coordinate of the light source, as seen in contour lines in Figure 4-26 and Figure 4-27.

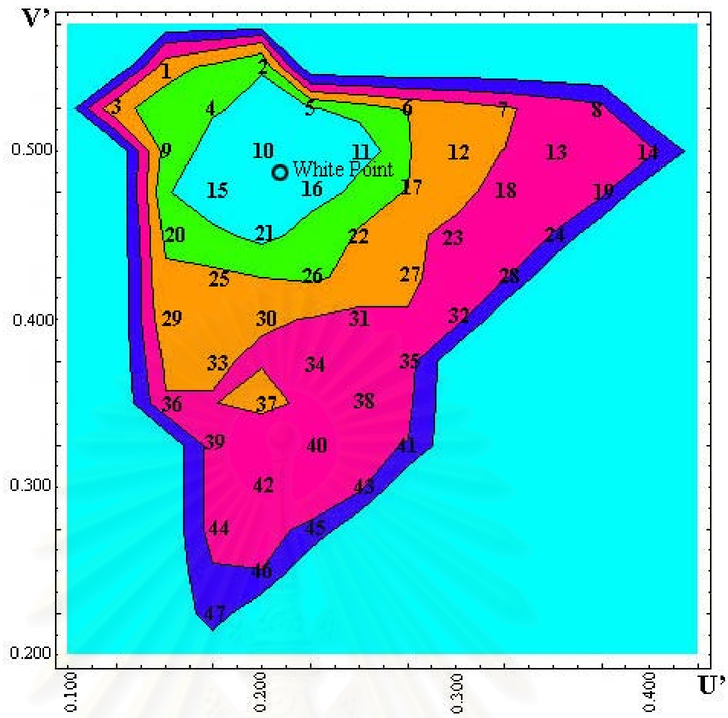


Figure 4-26 The contours lines of the matched luminance at 5 lux condition.

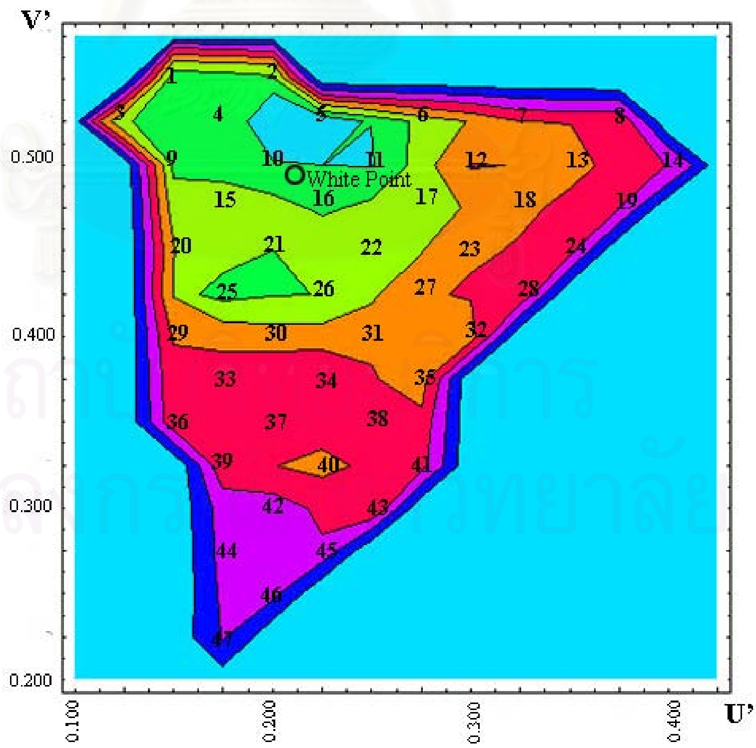


Figure 4-27 The contours lines of the matched luminance at 50 lux condition.

4.4 Comparison between the Border and the Brightness Matching

The objective of this research was to obtain the border luminance of RVSI by using CRT display as the test stimuli. From the result, found that the illuminance of observer's room limited the mode perception of color. Additional, the experiment was done for investigate the mechanism that determines the border. It was expected that the border would be closely related to brightness of the object, so that the heterochromatic brightness matching were used. The result of the border luminance and the brightness matching luminance will compare in this section.

Consider the result of two experiments, found that the curve tendencies were similar. Figure 4-28 and Figure 4-29, there are the comparison plotted of the border luminance and matched luminance at same illumination condition, the 5 lux and the 50 lux are shown respectively. Form the curves, found that the magnitude of the luminance in two experiments was quite different. It may cause the two reasons. The first, from the fact of the heterochromatic brightness matching, which say that when a test stimulus has been match in brightness against a fixed white reference stimulus, it is generally found that the luminance of chromatic test stimulus is lower than luminance of the reference stimulus [33]. The other reason is the luminance of N7 chart, that used as the white reference, had low lightness compare to the CRT stimulus. When the reference had low lightness that made the matched luminance became low. The result that all subjects detect may not reach the transition point of the color appearance mode. Form the result expect that if using more lightness of the white reference, for example using N8 or N9 Munsell chart, the matched luminance may high and reach the transition point.

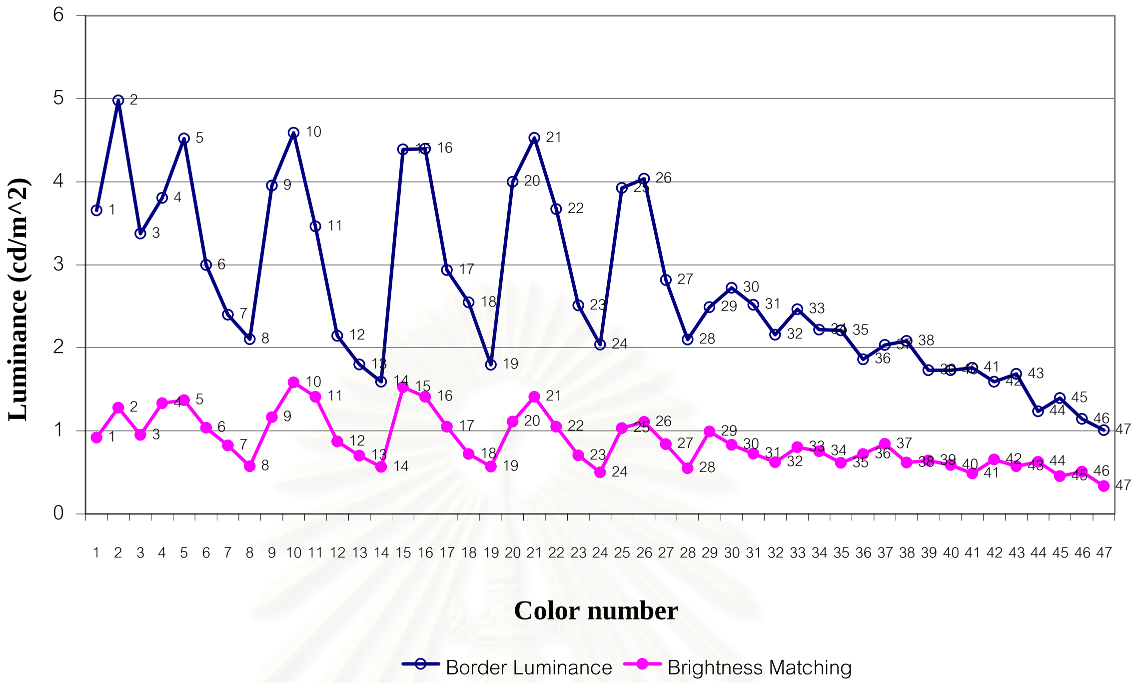


Figure 4-28 The comparison curves between the average border luminance and the average matched luminance of the CRT test stimuli at 5 lux illumination condition.

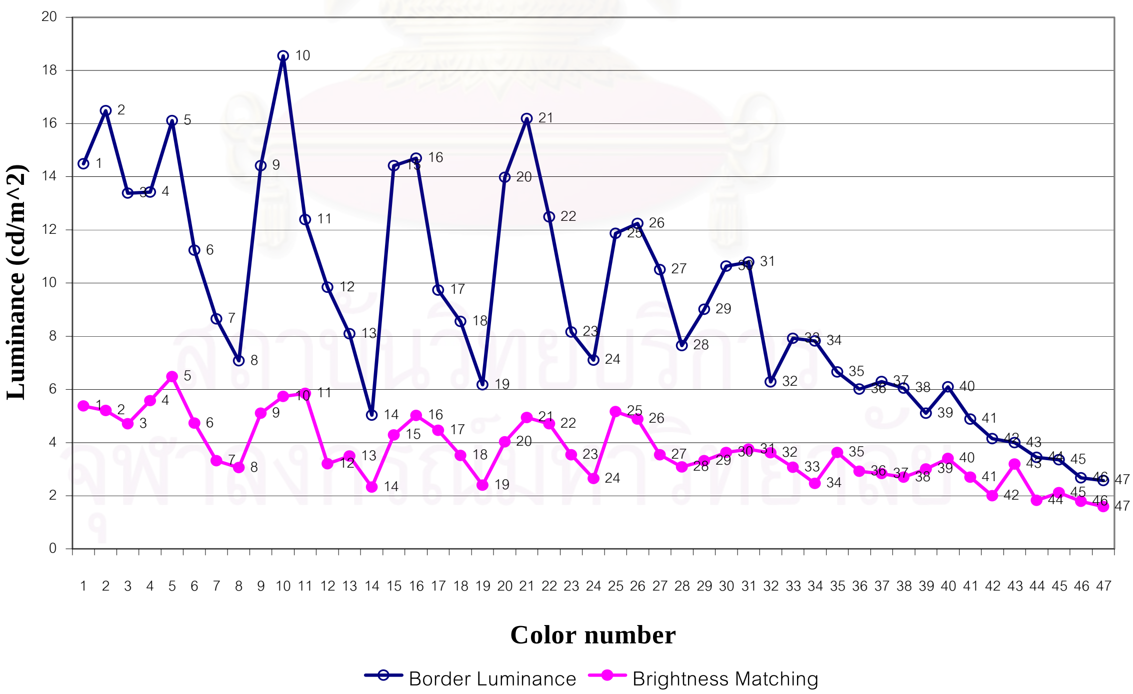


Figure 4-29 The comparison curves between the average border luminance and the average matched luminance of the CRT test stimuli at 50 lux illumination condition.

According to the results of the border luminance and matched luminance, normalization the data and plotted together in Figure 4-30 (for 5 lux condition) and Figure 4-31 (for 50 lux condition). The open circles represent the border luminance and filled circles represent the matched luminance. The shape of the curves were similar, the same in peak points and drop points.

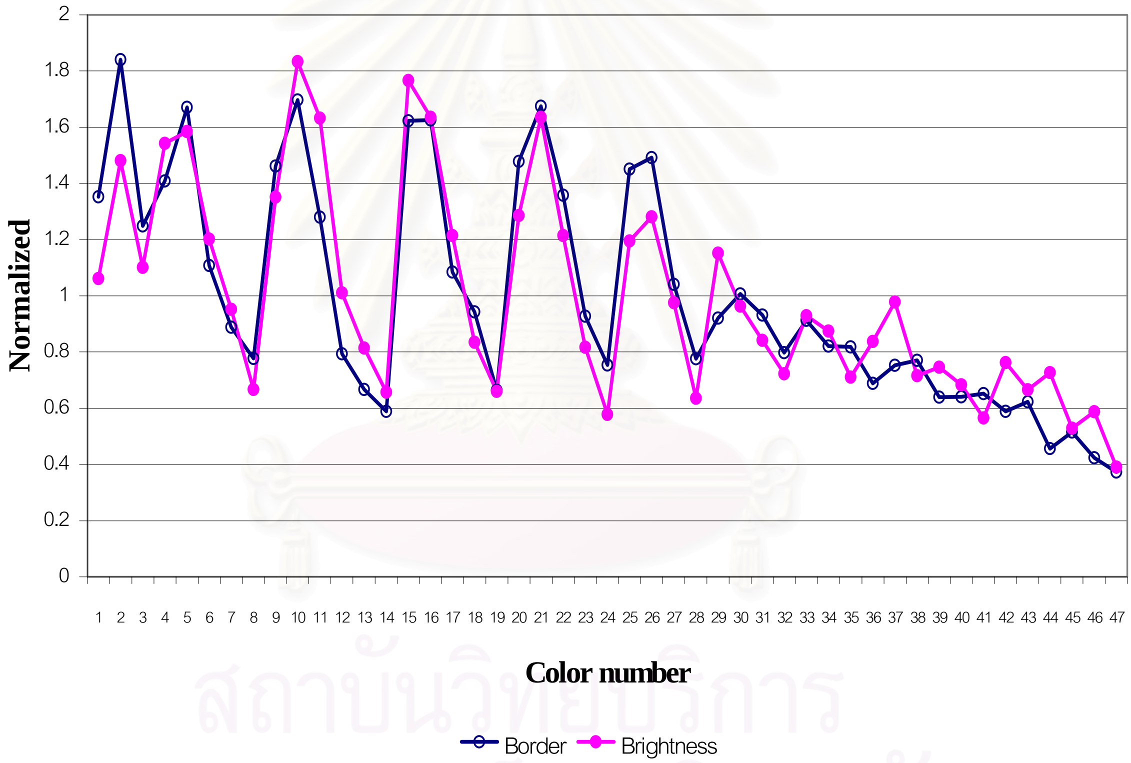


Figure 4-30 The normalized curves of the border luminance and the matched luminance of the CRT test stimuli at 5 lux illumination condition.

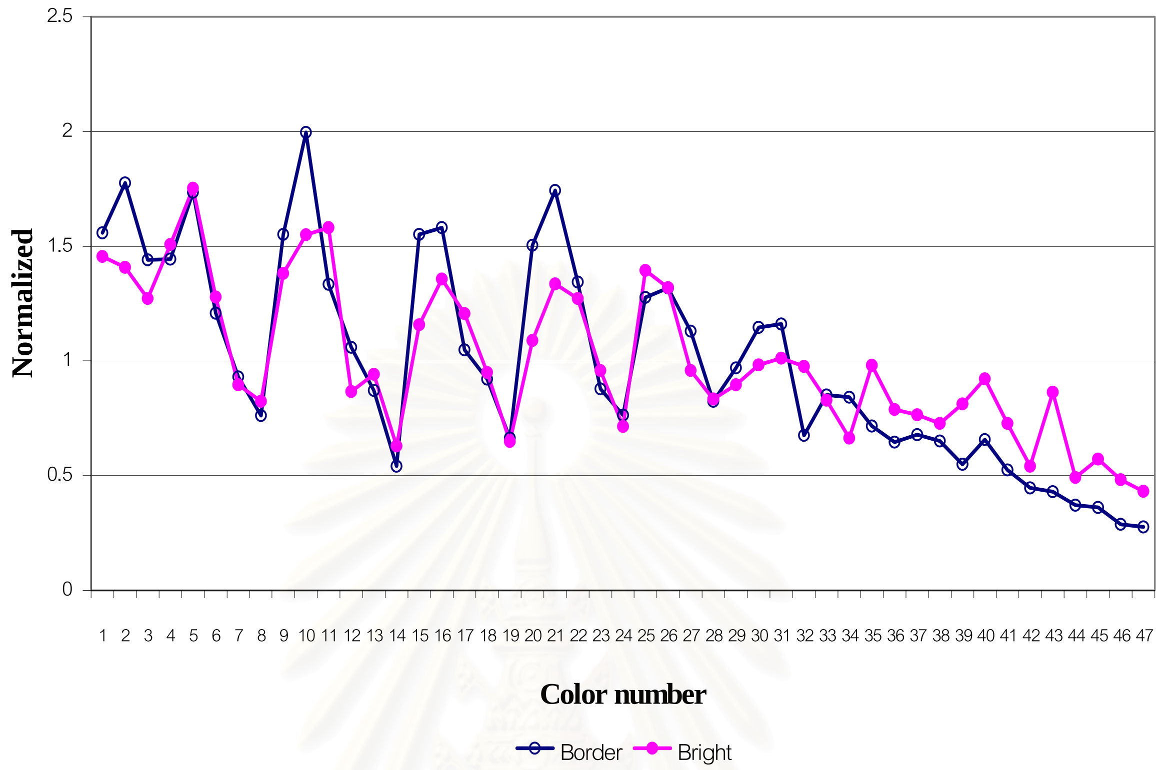


Figure 4-31 The normalized curves of the border luminance and the matched luminance of the CRT test stimuli at 50 lux illumination condition.

Plotted the average data from both experiments in the same space, the horizontal axis represent the border luminance and the vertical axis is represent the matched luminance, Figure 4-32 (5 lux) and Figure 4-33 (50 lux), the curve was shown as the linear. The linear equations were found with the correlation coefficient (R^2) of the 5 lux and the 50 lux were 0.8464 and 0.8207 respectively. These showed the border of RVSI and the brightness of test stimuli are relate. This may conclude that the border luminance determined by the brightness of the test stimuli as the first factor.

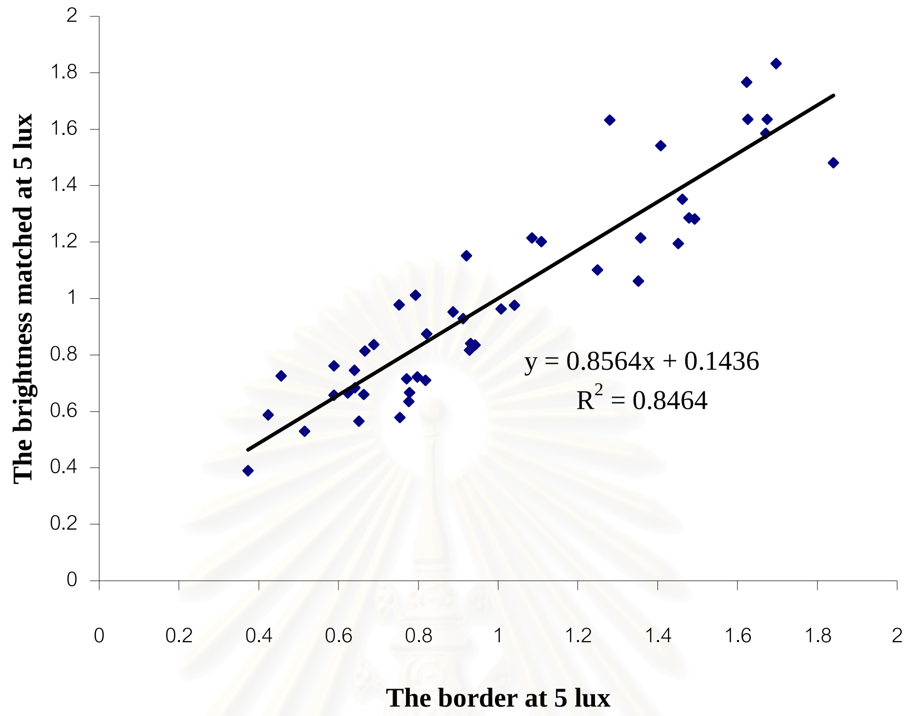


Figure 4-32 The relation between the border luminance and the matched luminance at 5 lux is found in linear relation

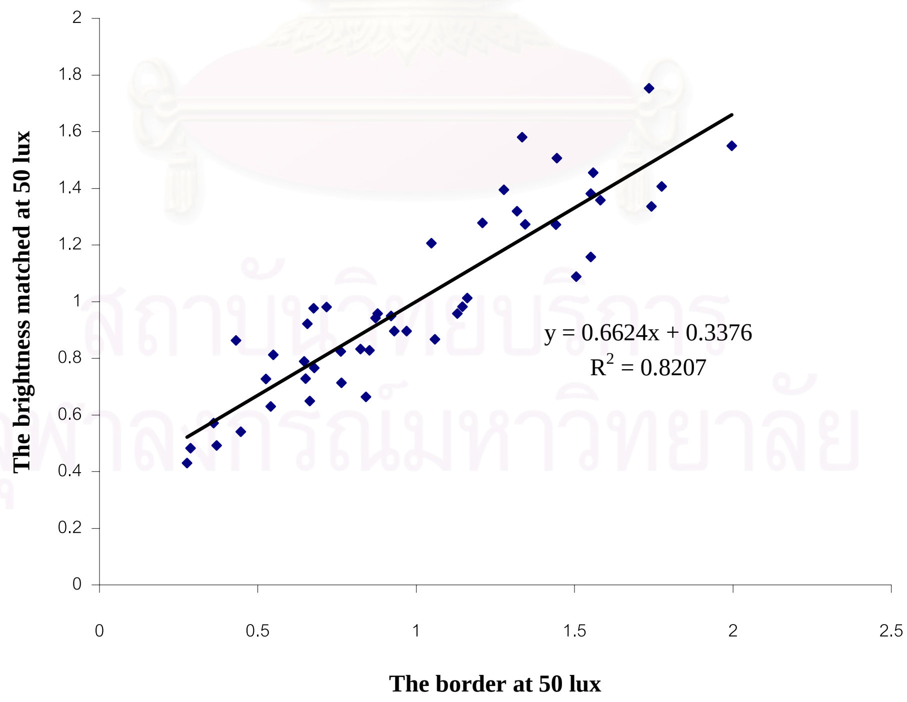


Figure 4-33 The relation between the border luminance and the matched luminance at 50 lux is found in linear relation

4.5 The Color Appearance Mode of CRT

The color appearance mode of the color that displayed on CRT monitor can change from the object color mode to the light source color mode. The brightness of the color and the observer's room illumination are the main factor. The result of the border experiment showed that, how high of the luminance for each test stimuli can be for display in the object color mode. That mean, the user can choose the mode of color appearance by control the luminance of the CRT display.

According to the border luminance data (Table 4-7), using equation Eq.(4-1) and the inverse equation of Eq.(4-2), the RGB code value of the border for 47 stimuli were obtained. The results are showed in Table 4-9, and the results has been plotted on the RGB color space as showed in Figure 4-34 for 5 lux condition and Figure 4-35 for 50 lux condition. The plotted showed the upper limited of the RGB values that displays the object mode on CRT monitor. If the RGB values are less than this value the color appear in the object color mode. If the RGB values that user used more than the RGB of the border, the CRT displays in the light source color mode. Note that, the upper limited of appearance mode depended on the luminance of observing room. For example the limited of 50 lux were higher than that of the 5 lux. The RGB border of the CRT are specific values for each device, these values are for the CRT that using in this experiment.

Table 4-9 the RGB code value at the border of RVSI

Color number	u'	v'	Border at 5 lux			Border at 50 lux		
			RED	*GREEN*	*BLUE*	*RED*	*GREEN*	*BLUE*
1	0.150	0.550	56	96	32	103	173	55
2	0.200	0.550	99	102	12	168	170	19
3	0.125	0.525	19	95	61	34	172	105
4	0.175	0.525	74	93	59	129	160	97
5	0.225	0.525	107	92	57	189	159	95
6	0.275	0.525	106	69	43	192	122	72
7	0.325	0.525	109	54	32	194	93	54
8	0.375	0.525	114	40	21	196	68	34
9	0.150	0.500	54	98	80	96	170	134
10	0.200	0.500	95	96	81	178	174	142
11	0.250	0.500	106	76	69	187	131	114
12	0.300	0.500	99	53	54	196	103	98
13	0.350	0.500	103	40	47	202	76	85
14	0.400	0.500	107	23	41	178	38	64
15	0.175	0.475	77	97	97	131	161	156
16	0.225	0.475	107	87	94	184	146	152
17	0.275	0.475	108	64	77	185	107	125
18	0.325	0.475	116	49	70	199	82	114
19	0.375	0.475	110	27	59	190	47	96
20	0.150	0.450	49	96	108	86	165	178
21	0.200	0.450	95	91	111	168	158	184
22	0.250	0.450	111	73	99	192	124	162
23	0.300	0.450	110	51	83	186	84	133
24	0.350	0.450	112	32	74	196	54	122
25	0.175	0.425	72	89	118	118	144	184
26	0.225	0.425	105	79	117	172	128	182
27	0.275	0.425	109	56	99	197	99	168
28	0.325	0.425	110	35	87	196	61	145
29	0.150	0.400	34	76	109	60	132	182
30	0.200	0.400	76	70	111	140	125	192
31	0.250	0.400	96	56	106	185	105	190
32	0.300	0.400	106	38	98	171	61	150
33	0.175	0.375	57	70	118	95	115	187
34	0.225	0.375	82	56	111	144	97	184
35	0.275	0.375	101	42	109	166	67	170

Table 4-9 the RGB code value at the border of RVSI (Continued)

Color number	u'	v'	Border at 5 lux			Border at 50 lux		
			RED	*GREEN*	*BLUE*	*RED*	*GREEN*	*BLUE*
36	0.150	0.350	21	65	115	34	107	183
37	0.200	0.350	67	57	117	112	93	184
38	0.250	0.350	91	44	117	147	69	179
39	0.175	0.325	47	56	119	75	89	184
40	0.225	0.325	75	44	118	132	75	195
41	0.275	0.325	95	22	118	150	34	176
42	0.200	0.300	61	45	124	93	68	181
43	0.250	0.300	86	26	125	127	38	177
44	0.175	0.275	38	43	121	59	67	182
45	0.225	0.275	71	28	125	105	41	178
46	0.200	0.250	53	29	125	78	42	176
47	0.175	0.225	31	31	129	47	47	187

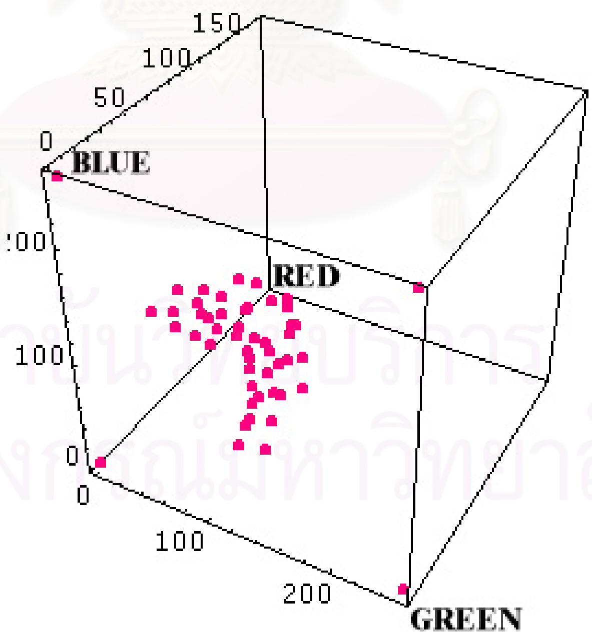


Figure 4-34 The border luminance of RVSI of the 5 lux condition, plotted on the RGB space

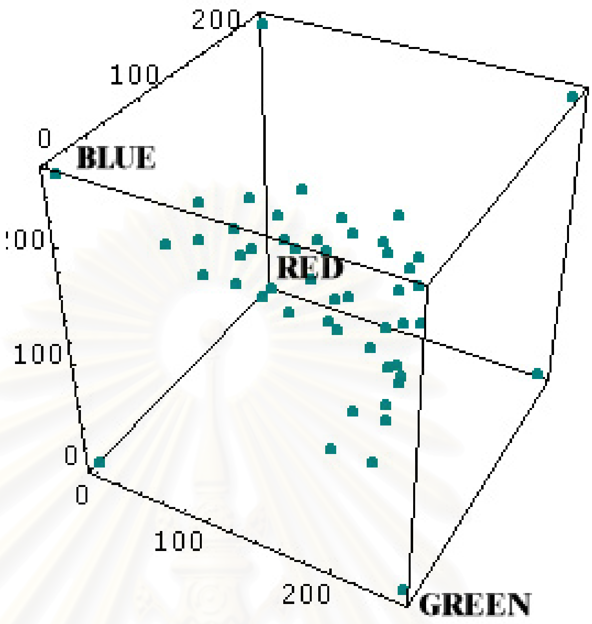


Figure 4-35 The border luminance of RVSI of the 5 lux condition,

plotted on the RGB space

The Look-Up-Table for program to control the CRT monitor will be create by using the data in Table 4-9. By the interpolation technique the RGB values for every colors on monitor can be find. From this method, the user can change the mode of color on the CRT monitor in what it want. In crease the RGB value more than the border value for the light source color mode and decrease the RGB value less than the border for the object color mode.

CHAPTER 5

CONCLUSION AND SUGGESTION

The border luminance of RVSI, the main propose, were obtained by determining the transition point of appearance mode from the object color mode to the light source color mode of CRT monitor. The data from all subjects quite clear that the border at 50 lux observer's room illumination condition was higher than 5 lux condition. Most of observer results showed the smaller standard deviation for the 5 lux compared to the 50 lux. The relationship between the border luminance and the room illuminance were found in linear with correlation coefficient of $R^2 = 0.9335$. This may conclude that the room illuminance limited the transition point of appearance mode. For a further study it is suggested that should be operated other room illuminance conditions in order to find the relationship of the CRT border luminance and room illumination.

The high border luminance was found in the test stimuli which has the colorimatic value closely to that of the light source illuminated in the observer's room. More saturated color had lower border luminance. The result implies that the color displayed on CRT can be changes their appearance depending on the illumination condition of the room. In the other words, the chromaticity of light source in the room influences the color appearance of the CRT monitor. A reason for the high border luminance was suggested that the variation of the chromaticity of light source are interesting to observe in proposes to predict the chromatic adaptation of

CRT display. The changes of the chromaticity of illumination in observer's room may changes the tendency of the border luminance on CRT display.

In this research, the heterochromatic brightness matching was used to investigate the brightness of test stimuli. The results of equal brightness between the test stimuli and white reference (Munsell N7 chart) were collected as the matched luminance. The results showed that the shape of the curves from both experiments was similar, their results implied that the brightness was the dominant factor to determine the border of RVSI. The matched luminance which obtained from the experiment had low magnitude compare to the border luminance, this was suggested that in a further experiment should be used the other white reference, N8 or N9 are recommend. The high lightness of white reference stimulus might be made high in the matched luminance and these may equal the border luminance.

The border luminance of RVSI of the CRT color monitor can be used in many applications. In any displaying images on CRT needs to see the real object and the natural appearance mode will appear like the real object. In this research indicated how high the luminance of CRT display should be for the object color appearance mode. The luminance of the CRT that displayed colors in the object color mode was found at the certain room illumination. In the other hand, the suitable RGB code values for displayed color in object mode at that room illumination were known.

The result of the experiment found the tendency of the border luminance for every color region correspond to the chromaticity diagram and monitor color gamut, that can help the user to select the color and the luminance for display the images, which look like the real object. Also for the color reproduction form a CRT to a print, the data can establish the same color appearance mode. If the color appearance mode between the CRT and printed are same, it will give the matched color on the printed as seen on the CRT monitor. That means, the CRT monitor can be used as the soft proof.

Moreover, in the result of this research showed that the color appearance mode and the observer's room illumination were related. The appearance change depending on the illumination condition. The result can apply to the color management systems as the option to collect data for monitor profile correctly. More consistent color appearance data of the CRT will be obtained, if the data collect under suitable lighting condition.

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APPENDICES

APPENDIX A

CIE Chromaticity of Test Stimuli

Table A-1 the information of the 47 color stimuli for the experimental

ColorNo.	u'	v'	x	y	L_{max}	R	G	B
1	0.150	0.550	0.329	0.537	35	153	253	78
2	0.200	0.550	0.409	0.500	41	253	252	27
3	0.125	0.525	0.259	0.483	33	51	254	150
4	0.175	0.525	0.339	0.452	39	208	254	149
5	0.225	0.525	0.409	0.424	31	254	210	123
6	0.275	0.525	0.471	0.400	21	254	159	93
7	0.325	0.525	0.527	0.378	15	248	118	67
8	0.375	0.525	0.577	0.359	12	248	85	42
9	0.150	0.500	0.276	0.408	36	145	252	193
10	0.200	0.500	0.346	0.385	41	254	245	194
11	0.250	0.500	0.409	0.364	25	256	177	151
12	0.300	0.500	0.466	0.345	17	251	130	122
13	0.350	0.500	0.516	0.328	13	249	93	103
14	0.400	0.500	0.563	0.313	11	253	53	88
15	0.175	0.475	0.289	0.349	41	209	253	237
16	0.225	0.475	0.352	0.330	30	253	199	202
17	0.275	0.475	0.409	0.314	20	255	145	166
18	0.325	0.475	0.461	0.299	14	248	101	139
19	0.375	0.475	0.508	0.286	11	246	60	121
20	0.150	0.450	0.237	0.316	34	128	241	254
21	0.200	0.450	0.300	0.300	36	241	223	253
22	0.250	0.450	0.357	0.286	23	252	161	207
23	0.300	0.450	0.409	0.273	16	251	113	174
24	0.350	0.450	0.457	0.261	12	249	68	151
25	0.175	0.425	0.252	0.272	26	167	201	251
26	0.225	0.425	0.309	0.260	28	250	182	254
27	0.275	0.425	0.361	0.248	18	250	125	208
28	0.325	0.425	0.409	0.238	13	248	77	179
29	0.150	0.400	0.208	0.246	20	86	187	251
30	0.200	0.400	0.265	0.235	21	190	168	252
31	0.250	0.400	0.317	0.225	22	254	143	252
32	0.300	0.400	0.365	0.216	15	253	88	213
33	0.175	0.375	0.223	0.213	17	134	160	254
34	0.225	0.375	0.276	0.204	17	204	135	251
35	0.275	0.375	0.324	0.196	17	252	101	247
36	0.150	0.350	0.185	0.192	13	48	149	249
37	0.200	0.350	0.237	0.184	14	160	131	253
38	0.250	0.350	0.285	0.177	14	214	100	250
39	0.175	0.325	0.201	0.166	11	106	124	250
40	0.225	0.325	0.248	0.160	11	172	96	247
41	0.275	0.325	0.293	0.154	12	225	49	253
42	0.200	0.300	0.214	0.143	9	132	95	247
43	0.250	0.300	0.259	0.138	9	183	53	244
44	0.175	0.275	0.182	0.127	8	86	97	254
45	0.225	0.275	0.226	0.123	8	154	59	252
46	0.200	0.250	0.196	0.109	6	112	59	243
47	0.175	0.225	0.167	0.095	5	63	62	244

Figure A-1 The test stimuli

Note: The color is depending on device,
the colors that seen in this Figure are different from the stimuli that seen on CRT

APPENDIX B

The Source Code of the Program

The source code of Program of display color stimuli. The code was for Visual Basic Version 6.

```
Dim u As Single
Dim v As Single
Dim X_Value As Single
Dim Y_Value As Single
Dim Yr As Single
Dim Yg As Single
Dim Yb As Single
Dim Scalar As Single
Dim Max As Single
Dim Mouse_Scroll As Boolean
Dim Control As Single
Dim newRecord As Boolean
Private Sub Command_Clear_Click()
Scale_Value = 0
R_Value = 0
G_Value = 0
B_Value = 0
Color_No = 0
Step = 0
End Sub

Private Sub Command_Down_Click()
If (R_Value < 0 Or G_Value < 0 Or B_Value < 0) Then
Response = MsgBox(" RGB Value Lower at 0 ", "1" + 48, "Warning...")
Else
If Scalar <= Max Then
Scalar = Scalar - Step
Yr = Scalar * ((0.706352 * (X_Value / Y_Value)) + (-0.31214) + (-0.10782 * (1 - X_Value - Y_Value)
/ Y_Value))
Yg = Scalar * ((-0.7108 * (X_Value / Y_Value)) + 1.33192 + (0.017161 * (1 - X_Value - Y_Value) /
Y_Value))
Yb = Scalar * ((0.004444 * (X_Value / Y_Value)) + (-0.01978) + (0.090664 * (1 - X_Value -
Y_Value) / Y_Value))
```

```
R_Value = 255 * ((Yr / 10.3) ^ (1 / 2.2219) + 0.0037) / 1.0019
G_Value = 255 * ((Yg / 32.2) ^ (1 / 2.3245) + 0.0008) / 1.0006
B_Value = 255 * ((Yb / 3.83) ^ (1 / 2.4989) + 0.0013) / 1.0041
Scale_Value = Scalar
Else
Scalar = Scalar - 1
End If
End If
Picture_color.BackColor = RGB(R_Value, G_Value, B_Value)
End Sub

Private Sub Command_Exit_Click()
Unload Me
End Sub

Private Sub Command_No_Click()
Select Case Color_No
Case 1
u = 0.15
v = 0.55
Max = 35
Case 2
u = 0.2
v = 0.55
Max = 41
Case 3
u = 0.125
v = 0.525
Max = 33
Case 4
u = 0.175
v = 0.525
Max = 39
Case 5
u = 0.225
v = 0.525
Max = 31
Case 6
```

u = 0.275

v = 0.525

Max = 21

Case 7

u = 0.325

v = 0.525

Max = 16

Case 8

u = 0.375

v = 0.525

Max = 13

Case 9

u = 0.15

v = 0.5

Max = 36

Case 10

u = 0.2

v = 0.5

Max = 41

Case 11

u = 0.25

v = 0.5

Max = 25

Case 12

u = 0.3

v = 0.5

Max = 18

Case 13

u = 0.35

v = 0.5

Max = 14

Case 14

u = 0.4

v = 0.5

Max = 11

Case 15

u = 0.175

v = 0.475

Max = 42

Case 16

u = 0.225

v = 0.475

Max = 30

Case 17

u = 0.275

v = 0.475

Max = 20

Case 18

u = 0.325

v = 0.475

Max = 15

Case 19

u = 0.375

v = 0.475

Max = 12

Case 20

u = 0.15

v = 0.45

Max = 34

Case 21

u = 0.2

v = 0.45

Max = 36

Case 22

u = 0.25

v = 0.45

Max = 23

Case 23

u = 0.3

v = 0.45

Max = 16

Case 24

u = 0.35

v = 0.45

Max = 13

Case 25

u = 0.175

v = 0.425

Max = 27

Case 26

u = 0.225

v = 0.425

Max = 28

Case 27

u = 0.275

v = 0.425

Max = 19

Case 28

u = 0.325

v = 0.425

Max = 14

Case 29

u = 0.15

v = 0.4

Max = 21

Case 30

u = 0.2

v = 0.4

Max = 22

Case 31

u = 0.25

v = 0.4

Max = 22

Case 32

u = 0.3

v = 0.4

Max = 15

Case 33

u = 0.175

v = 0.375

Max = 17

Case 34

u = 0.225

v = 0.375

Max = 17

Case 35

u = 0.275

v = 0.375

Max = 17

Case 36

u = 0.15

v = 0.35

Max = 14

Case 37

u = 0.2

v = 0.35

Max = 14

Case 38

u = 0.25

v = 0.35

Max = 14

Case 39

u = 0.175

v = 0.325

Max = 12

Case 40

u = 0.225

v = 0.325

Max = 12

Case 41

u = 0.275

v = 0.325

Max = 12

Case 42

u = 0.2

v = 0.3

Max = 10

Case 43

u = 0.25

v = 0.3

Max = 10

Case 44

```
u = 0.175
v = 0.275
Max = 8
Case 45
u = 0.225
v = 0.275
Max = 8
Case 46
u = 0.2
v = 0.25
Max = 6
Case 47
u = 0.175
v = 0.225
Max = 6
Case 48
u = 0.25
v = 0.525
Case 49
u = 0.225
v = 0.5
Case 50
u = 0.2
v = 0.425
Case Else
Response = MsgBox(" Enter Number 1-50 ", "0" + 48, "Warning...")
End Select
X_Value = (27 * u) / (18 * u - 48 * v + 36)
Y_Value = (12 * v) / (18 * u - 48 * v + 36)
Scalar = 1
Scale_Value = Scalar
Yr = Scalar * ((0.706352 * (X_Value / Y_Value)) + (-0.31214) + (-0.10782 * (1 - X_Value - Y_Value) / Y_Value))
Yg = Scalar * ((-0.7108 * (X_Value / Y_Value)) + 1.33192 + (0.017161 * (1 - X_Value - Y_Value) / Y_Value))
Yb = Scalar * ((0.004444 * (X_Value / Y_Value)) + (-0.01978) + (0.090664 * (1 - X_Value - Y_Value) / Y_Value))
R_Value = 255 * ((Yr / 10.3) ^ (1 / 2.2219) + 0.0037) / 1.0019
```

```
G_Value = 255 * ((Yg / 32.2) ^ (1 / 2.3245) + 0.0008) / 1.0006
B_Value = 255 * ((Yb / 3.83) ^ (1 / 2.4989) + 0.0013) / 1.0041
Picture_color.BackColor = RGB(R_Value, G_Value, B_Value)

End Sub

Private Sub Command_Save_Click()
With Data1.Recordset
If newRecord = True Then
.AddNew
End If
![Color] = Color_No
![RED] = R_Value
![GREEN] = G_Value
![BLUE] = B_Value
![Scalar] = Scale_Value
![u] = u
![v] = v
![X] = X_Value
![Y] = Y_Value
.Update
End With
newRecord = False
End Sub

Private Sub Command_Up_Click()
Picture_color.BackColor = RGB(R_Value, G_Value, B_Value)
If Scalar < 0 Then
Response = MsgBox(" RGB Value Lower at 0 ", "1" + 48, "Warning...")
Else
If Scalar <= Max Then
Scalar = Scalar + Step
Yr = Scalar * ((0.706352 * (X_Value / Y_Value)) + (-0.31214) + (-0.10782 * (1 - X_Value - Y_Value)
/ Y_Value))
Yg = Scalar * ((-0.7108 * (X_Value / Y_Value)) + 1.33192 + (0.017161 * (1 - X_Value - Y_Value) /
Y_Value))
Yb = Scalar * ((0.004444 * (X_Value / Y_Value)) + (-0.01978) + (0.090664 * (1 - X_Value -
Y_Value) / Y_Value))
```

```
R_Value = 255 * ((Yr / 10.3) ^ (1 / 2.2219) + 0.0037) / 1.0019
G_Value = 255 * ((Yg / 32.2) ^ (1 / 2.3245) + 0.0008) / 1.0006
B_Value = 255 * ((Yb / 3.83) ^ (1 / 2.4989) + 0.0013) / 1.0041
Scale_Value = Scalar
Else
Response = MsgBox(" RGB Value higher at 255 ", "1" + 48, "Warning...")
End If
End If
Picture_color.BackColor = RGB(R_Value, G_Value, B_Value)
End Sub

Private Sub Command_View_Click()
If Color_No = 0 Then
Picture_color.BackColor = RGB(R_Value, G_Value, B_Value)
Else
Select Case Color_No
Case 1
u = 0.15
v = 0.55
Max = 35
Case 2
u = 0.2
v = 0.55
Max = 41
Case 3
u = 0.125
v = 0.525
Max = 33
Case 4
u = 0.175
v = 0.525
Max = 39
Case 5
u = 0.225
v = 0.525
Max = 31
Case 6
u = 0.275
```

v = 0.525

Max = 21

Case 7

u = 0.325

v = 0.525

Max = 16

Case 8

u = 0.375

v = 0.525

Max = 13

Case 9

u = 0.15

v = 0.5

Max = 36

Case 10

u = 0.2

v = 0.5

Max = 41

Case 11

u = 0.25

v = 0.5

Max = 25

Case 12

u = 0.3

v = 0.5

Max = 18

Case 13

u = 0.35

v = 0.5

Max = 14

Case 14

u = 0.4

v = 0.5

Max = 11

Case 15

u = 0.175

v = 0.475

Max = 42

Case 16

u = 0.225

v = 0.475

Max = 30

Case 17

u = 0.275

v = 0.475

Max = 20

Case 18

u = 0.325

v = 0.475

Max = 15

Case 19

u = 0.375

v = 0.475

Max = 12

Case 20

u = 0.15

v = 0.45

Max = 34

Case 21

u = 0.2

v = 0.45

Max = 36

Case 22

u = 0.25

v = 0.45

Max = 23

Case 23

u = 0.3

v = 0.45

Max = 16

Case 24

u = 0.35

v = 0.45

Max = 13

Case 25

u = 0.175

v = 0.425

Max = 27

Case 26

u = 0.225

v = 0.425

Max = 28

Case 27

u = 0.275

v = 0.425

Max = 19

Case 28

u = 0.325

v = 0.425

Max = 14

Case 29

u = 0.15

v = 0.4

Max = 21

Case 30

u = 0.2

v = 0.4

Max = 22

Case 31

u = 0.25

v = 0.4

Max = 22

Case 32

u = 0.3

v = 0.4

Max = 15

Case 33

u = 0.175

v = 0.375

Max = 17

Case 34

u = 0.225

v = 0.375

Max = 17

Case 35

u = 0.275

v = 0.375

Max = 17

Case 36

u = 0.15

v = 0.35

Max = 14

Case 37

u = 0.2

v = 0.35

Max = 14

Case 38

u = 0.25

v = 0.35

Max = 14

Case 39

u = 0.175

v = 0.325

Max = 12

Case 40

u = 0.225

v = 0.325

Max = 12

Case 41

u = 0.275

v = 0.325

Max = 12

Case 42

u = 0.2

v = 0.3

Max = 10

Case 43

u = 0.25

v = 0.3

Max = 10

Case 44

u = 0.175

```
v = 0.275
Max = 8
Case 45
u = 0.225
v = 0.275
Max = 8
Case 46
u = 0.2
v = 0.25
Max = 6
Case 47
u = 0.175
v = 0.225
Max = 6
Case 48
u = 0.25
v = 0.525
Case 49
u = 0.225
v = 0.5
Case 50
u = 0.2
v = 0.425
Case Else
Response = MsgBox(" Enter Number 1-50 ", "0" + 48, "Warning...")
End Select
X_Value = (27 * u) / (18 * u - 48 * v + 36)
Y_Value = (12 * v) / (18 * u - 48 * v + 36)
Scalar = Scale_Value
Scale_Value = Scalar
Yr = Scalar * ((0.706352 * (X_Value / Y_Value)) + (-0.31214) + (-0.10782 * (1 - X_Value - Y_Value)
/ Y_Value))
Yg = Scalar * ((-0.7108 * (X_Value / Y_Value)) + 1.33192 + (0.017161 * (1 - X_Value - Y_Value) /
Y_Value))
Yb = Scalar * ((0.004444 * (X_Value / Y_Value)) + (-0.01978) + (0.090664 * (1 - X_Value -
Y_Value) / Y_Value))
R_Value = 255 * ((Yr / 10.3) ^ (1 / 2.2219) + 0.0037) / 1.0019
G_Value = 255 * ((Yg / 32.2) ^ (1 / 2.3245) + 0.0008) / 1.0006
```

```
B_Value = 255 * ((Yb / 3.83) ^ (1 / 2.4989) + 0.0013) / 1.0041
Picture_color.BackColor = RGB(R_Value, G_Value, B_Value)
End If
End Sub

Private Sub Form_Load()
R_Value = 0
G_Value = 0
B_Value = 0
Color_No = 0
Step = 0
Scale_Value = 0

End Sub

Private Sub Picture_color_Click()
Mouse_Scroll = True
newRecord = True
End Sub

Private Sub Picture_color_DblClick()
Mouse_Scroll = False
Response = MsgBox("Save This Value as The BORDER?", vbQuestion + vbOKCancel +
vbDefaultButton1, "THE BORDER")
If Response = vbOK Then
With Data1.Recordset
If newRecord = True Then
.AddNew
End If
![Color] = Color_No
![RED] = R_Value
![GREEN] = G_Value
![BLUE] = B_Value
![Scalar] = Scale_Value
![u] = u
![v] = v
![X] = X_Value
![Y] = Y_Value
```

```
.Update
End With
newRecord = False
End If
Color_No.SetFocus
End Sub

Private Sub Picture_color_MouseMove(Button As Integer, Shift As Integer, X As Single, Y As Single)
If Mouse_Scroll Then
Scale_Value = Max * X / 11800
Scalar = Scale_Value
Yr = Scalar * ((0.706352 * (X_Value / Y_Value)) + (-0.31214) + (-0.10782 * (1 - X_Value - Y_Value)
/ Y_Value))
Yg = Scalar * ((-0.7108 * (X_Value / Y_Value)) + 1.33192 + (0.017161 * (1 - X_Value - Y_Value) /
Y_Value))
Yb = Scalar * ((0.004444 * (X_Value / Y_Value)) + (-0.01978) + (0.090664 * (1 - X_Value -
Y_Value) / Y_Value))
R_Value = 255 * ((Yr / 10.3) ^ (1 / 2.2219) + 0.0037) / 1.0019
G_Value = 255 * ((Yg / 32.2) ^ (1 / 2.3245) + 0.0008) / 1.0006
B_Value = 255 * ((Yb / 3.83) ^ (1 / 2.4989) + 0.0013) / 1.0041
Picture_color.BackColor = RGB(R_Value, G_Value, B_Value)
End If
End Sub
```

Figure B-1 The user interface of programmed

The color display by input the number of test stimulus. To change the stimulus luminance by move mouse on the display area for increase move mouse to right and move left for decrease the luminance of test stimulus. The luminance of the stimulus will display on the screen. The commands UP and Down are the other way for increase and decrease the luminance of stimulus. When the subject found the transition point, the border of RVSI, double click on the display area the RGB code value and the luminance are shows. Also the data will collect on the linked document.

APPENDIX C

The Data of The Border RVSI Experiment

Table C-1a the border experimental data of subject KJ at condition 5 lux illumination.

No.	1	2	3	4	5	6	7	8	9	10	Average	Stnd Div
1	7.59	6.71	3.34	3.41	6.03	6.89	4.44	5.94	6.87	6.05	5.726	1.49
2	7.69	6.12	2.82	6.42	5.45	6.28	6.05	5.22	6.88	3.55	5.648	1.48
3	5.94	7.80	4.54	7.14	6.31	4.54	4.54	7.13	6.30	6.01	6.025	1.17
4	7.19	6.15	4.92	7.22	6.89	6.29	6.64	4.36	6.85	4.69	6.119	1.07
5	6.89	6.34	5.88	6.38	7.30	6.89	6.38	6.77	5.47	6.05	6.433	0.55
6	3.47	2.51	1.94	3.77	2.60	1.85	3.54	2.68	1.94	3.54	2.785	0.75
7	2.20	3.29	2.22	2.20	1.76	2.63	2.70	2.78	2.39	2.30	2.446	0.42
8	0.59	1.46	2.16	0.82	1.49	1.86	1.97	1.57	1.97	1.94	1.584	0.52
9	5.76	5.26	5.72	5.20	4.26	5.22	5.93	4.97	5.75	5.75	5.380	0.51
10	8.82	9.34	4.73	9.19	8.51	7.70	6.01	8.52	9.17	9.14	8.113	1.55
11	11.4	2.94	6.70	7.70	6.85	6.80	6.37	7.15	6.48	6.05	6.850	2.07
12	1.20	1.64	1.66	1.67	1.77	2.97	2.11	2.71	2.04	1.94	1.971	0.53
13	1.05	1.62	2.86	1.14	2.72	1.02	0.93	1.11	0.82	1.11	1.436	0.74
14	0.80	2.31	1.99	0.83	0.93	1.11	0.82	0.82	0.94	2.31	1.285	0.64
15	4.05	6.32	4.67	6.05	5.30	5.86	5.21	5.85	5.46	5.21	5.397	0.68
16	1.59	3.50	4.58	5.44	3.53	4.39	5.71	6.00	5.38	4.52	4.463	1.33
17	3.35	3.88	7.56	3.61	3.77	4.36	2.71	5.21	3.81	4.38	4.264	1.34
18	4.91	3.56	4.12	3.44	4.27	3.30	3.61	3.64	4.38	2.71	3.792	0.63
19	1.75	1.54	2.33	1.93	1.65	1.21	1.94	1.55	2.33	1.66	1.788	0.35
20	4.97	4.57	5.87	4.38	6.27	5.27	6.04	4.52	4.99	5.20	5.209	0.66
21	4.81	2.78	10.5	4.90	5.21	6.05	6.89	6.03	5.21	4.63	5.703	2.01
22	6.80	2.53	5.12	6.11	5.21	3.77	5.26	5.21	6.11	5.21	5.132	1.22
23	3.53	4.39	4.35	3.13	1.86	3.55	2.71	3.60	5.44	4.69	3.724	1.04
24	2.78	2.91	2.92	2.41	2.78	3.12	2.91	3.55	4.39	1.77	2.953	0.68
25	3.80	5.12	7.49	6.89	5.20	6.27	5.27	4.44	3.55	6.89	5.492	1.35
26	6.50	7.42	7.86	7.71	6.86	6.02	8.21	8.55	7.97	7.46	7.455	0.79
27	2.86	2.33	5.49	3.55	5.27	4.63	3.77	4.44	5.19	3.53	4.106	1.07
28	3.50	3.99	2.18	1.94	1.76	1.69	3.44	2.52	1.67	2.68	2.536	0.84
29	1.71	2.96	3.31	2.72	1.68	2.93	2.85	2.33	2.94	3.31	2.674	0.59
30	4.29	6.83	1.68	4.25	4.36	2.68	4.44	2.72	3.44	4.37	3.906	1.40
31	1.91	2.17	1.61	1.91	2.17	1.91	1.66	1.61	1.91	2.20	1.905	0.23
32	1.75	2.26	1.02	2.01	2.25	2.02	1.03	1.78	1.03	1.94	1.707	0.50
33	2.27	3.73	1.69	2.32	3.68	1.69	2.68	2.93	2.41	1.85	2.526	0.74
34	2.34	2.20	1.44	1.58	2.13	2.21	1.64	1.75	2.39	1.49	1.916	0.37
35	2.85	1.55	2.95	2.85	1.94	3.02	1.65	2.22	2.60	2.22	2.384	0.55
36	0.74	0.73	1.01	0.75	0.82	1.14	0.93	1.13	1.68	1.65	1.057	0.35
37	2.12	1.66	2.55	2.32	2.50	1.64	1.69	2.52	2.40	2.38	2.177	0.38
38	1.97	1.62	3.14	2.10	1.94	2.77	1.89	2.71	1.76	1.97	2.187	0.50
39	0.84	1.45	1.11	1.03	1.58	1.05	1.29	1.94	1.79	1.67	1.373	0.37
40	1.05	0.93	0.80	0.72	0.94	1.11	2.14	1.80	0.72	0.54	1.074	0.51
41	1.33	1.56	2.24	2.32	1.44	1.93	1.55	1.35	1.49	2.21	1.742	0.39
42	1.31	1.40	1.11	1.05	1.46	1.65	1.05	1.14	2.21	0.72	1.309	0.41
43	1.60	2.25	1.94	2.47	1.55	1.63	2.13	2.17	0.90	2.38	1.902	0.48
44	0.65	1.49	0.66	0.65	0.74	0.80	1.54	1.03	0.86	0.82	0.925	0.33
45	3.43	2.60	2.67	2.69	1.88	3.05	1.94	1.38	1.94	1.89	2.346	0.64
46	0.83	1.04	0.83	0.83	1.03	1.02	1.11	0.71	0.63	0.93	0.894	0.16
47	1.65	1.68	1.53	1.05	1.32	0.38	1.05	0.71	0.86	0.82	1.104	0.43
										Mean	*3.388*	*0.78*

Table C-1b the border experimental data of subject KJ at condition 50 lux illumination.

No.	1	2	3	4	5	6	7	8	9	10	Average	Stnd Div
1	13.30	8.72	11.39	11.24	12.55	9.27	13.25	10.27	13.27	10.10	11.34	1.72
2	6.25	6.51	10.16	10.27	6.23	7.16	10.24	8.25	9.10	6.45	8.06	1.75
3	8.47	13.42	11.75	13.27	14.24	13.22	13.41	12.25	11.26	9.26	12.06	1.91
4	10.36	12.27	16.36	13.26	14.25	16.24	10.22	11.33	10.33	12.36	12.70	2.31
5	14.86	13.63	15.88	14.66	15.63	16.33	15.45	13.85	14.65	15.24	15.02	0.86
6	12.09	14.36	12.44	13.27	14.23	14.63	14.99	15.02	13.22	14.27	13.85	1.04
7	6.43	5.72	7.79	7.56	5.69	6.45	7.24	5.13	7.24	6.24	6.55	0.89
8	3.75	7.30	5.59	3.25	5.12	3.79	3.99	4.25	5.24	5.56	4.78	1.21
9	11.94	12.81	13.09	10.23	11.59	12.36	12.81	13.00	11.03	10.66	11.95	1.03
10	14.91	13.71	9.07	14.91	13.27	14.65	13.27	12.25	13.27	10.27	12.96	1.95
11	11.03	9.25	9.95	10.33	11.24	9.86	10.63	9.89	10.52	11.53	10.42	0.71
12	3.84	7.18	6.02	6.54	7.01	3.24	4.23	3.66	4.58	6.25	5.26	1.50
13	10.73	8.77	4.73	4.33	6.22	3.22	4.10	3.57	3.55	4.33	5.36	2.50
14	4.26	4.87	3.52	3.54	4.11	3.85	4.63	3.27	2.13	2.97	3.71	0.82
15	13.83	10.89	9.40	12.25	13.63	12.33	10.97	9.65	10.25	11.03	11.42	1.54
16	7.51	8.50	7.93	8.05	7.63	8.53	6.23	8.43	6.33	8.69	7.79	0.88
17	7.83	7.53	8.24	7.27	5.24	6.23	7.25	6.85	5.27	7.27	6.90	1.02
18	8.54	7.97	9.86	9.90	8.22	7.24	6.26	7.27	8.24	7.23	8.07	1.16
19	4.82	7.41	7.67	4.55	5.64	4.67	5.24	6.21	7.66	5.02	5.89	1.27
20	7.74	6.48	11.84	10.63	7.87	9.27	11.25	10.27	12.37	10.56	9.83	1.93
21	5.45	8.24	7.55	8.87	9.13	10.23	8.33	10.23	8.27	9.33	8.56	1.39
22	4.30	11.78	15.14	11.33	9.33	6.33	7.27	8.33	9.27	10.27	9.33	3.06
23	5.31	4.29	5.17	4.37	5.56	5.24	4.21	4.11	4.88	5.02	4.81	0.52
24	5.80	6.20	4.23	5.03	4.05	4.23	4.67	7.27	5.03	4.88	5.14	1.01
25	5.15	3.98	5.70	6.03	5.97	3.25	3.23	5.66	6.33	6.25	5.16	1.21
26	3.56	9.36	7.12	9.27	8.23	7.26	8.63	7.27	8.27	7.90	7.68	1.65
27	10.72	11.86	14.88	10.33	9.86	9.56	10.27	11.26	10.24	9.26	10.82	1.62
28	6.58	6.86	7.21	6.50	7.27	7.56	6.33	7.00	6.24	6.23	6.78	0.47
29	7.98	9.16	8.12	7.10	8.24	9.03	7.23	7.85	9.25	8.13	8.21	0.75
30	5.09	5.12	6.63	6.66	5.24	6.12	5.55	4.53	5.22	4.25	5.44	0.81
31	10.93	9.79	10.07	10.67	11.25	9.66	11.23	10.27	8.25	9.12	10.12	0.96
32	4.84	4.94	6.27	4.52	6.24	5.52	4.33	3.99	4.25	4.52	4.94	0.81
33	3.11	3.70	3.65	3.12	3.23	3.12	2.97	3.13	3.11	2.96	3.21	0.26
34	5.62	3.31	8.08	5.24	3.30	5.23	4.23	5.33	5.27	5.57	5.12	1.36
35	2.53	4.08	2.96	2.33	2.10	2.00	2.37	3.45	4.52	3.27	2.96	0.86
36	3.63	4.63	4.02	3.23	4.26	3.23	4.33	3.27	3.26	3.13	3.70	0.56
37	7.03	7.92	6.98	6.33	7.02	6.24	7.24	6.10	6.90	6.27	6.80	0.57
38	3.10	3.38	3.20	3.23	3.27	4.00	3.97	3.00	2.33	2.13	3.16	0.60
39	2.88	2.62	4.56	2.34	2.15	2.37	3.27	2.54	2.00	3.22	2.79	0.75
40	2.47	3.74	4.26	2.22	3.25	3.27	2.21	2.00	3.24	2.22	2.89	0.77
41	2.47	3.05	3.39	3.01	3.22	2.22	2.37	3.03	3.32	2.20	2.83	0.46
42	1.73	5.21	3.99	1.25	2.33	3.23	1.27	2.21	1.53	2.24	2.50	1.29
43	2.49	2.53	4.02	2.55	2.63	2.23	2.33	3.23	4.27	1.27	2.75	0.88
44	2.52	1.64	2.92	1.02	2.33	1.00	2.23	2.63	2.96	2.23	2.15	0.71
45	2.23	1.80	2.09	1.56	2.02	1.63	1.22	1.24	1.33	1.00	1.61	0.42
46	0.86	2.84	2.62	0.87	1.21	0.88	0.97	1.23	1.11	0.88	1.35	0.75
47	1.71	2.69	3.33	1.53	2.21	1.66	1.66	1.99	2.02	2.22	2.10	0.55
										Mean	*6.74*	*1.13*

Table C-2a the border experimental data of subject NJ at condition 5 lux illumination.

No.	1	2	3	4	5	6	7	8	9	10	Average	Stnd Div
1	2.49	2.41	2.58	2.63	1.87	2.09	3.16	2.80	2.80	2.41	2.52	0.37
2	3.13	4.22	4.12	2.09	2.19	3.44	3.13	3.08	2.35	2.09	2.98	0.80
3	2.56	2.64	2.14	1.97	1.09	2.52	4.10	2.83	2.89	2.64	2.54	0.76
4	2.18	1.93	3.42	1.83	2.38	2.83	1.93	2.19	3.42	1.83	2.40	0.62
5	3.90	3.03	2.92	1.62	2.52	4.22	3.90	3.03	2.92	3.00	3.11	0.76
6	3.28	3.36	2.80	3.60	2.24	2.49	3.28	3.37	2.80	2.25	2.95	0.50
7	2.05	3.66	3.36	1.85	3.03	2.34	2.05	3.36	3.03	3.13	2.79	0.65
8	2.33	2.23	3.40	0.88	1.11	1.45	1.24	2.33	3.02	1.24	1.92	0.87
9	4.16	4.56	4.48	2.29	3.16	3.52	4.52	4.13	4.45	3.15	3.84	0.78
10	2.66	2.35	3.12	2.08	3.75	2.97	2.35	3.13	2.09	2.66	2.71	0.53
11	1.62	2.19	2.26	4.89	3.69	4.42	4.13	2.33	2.33	4.33	3.22	1.18
12	2.29	2.44	2.15	2.47	2.75	1.92	2.28	2.48	2.15	2.00	2.29	0.25
13	1.48	2.15	1.99	1.74	1.19	2.05	2.15	1.74	2.37	1.63	1.85	0.36
14	1.02	1.33	1.19	1.06	0.98	1.05	1.02	1.33	1.24	1.00	1.12	0.14
15	2.30	3.95	3.20	5.50	1.39	4.16	3.46	3.87	3.22	2.33	3.34	1.15
16	2.52	4.12	3.24	2.56	2.44	4.04	3.56	2.89	3.25	3.70	3.23	0.62
17	1.73	1.58	2.17	2.06	2.21	1.91	2.06	2.06	2.21	1.91	1.99	0.21
18	2.44	3.39	3.09	3.33	3.45	2.33	2.13	2.37	2.44	3.39	2.84	0.54
19	1.21	1.11	1.57	1.24	1.65	1.33	1.27	1.53	1.65	1.33	1.39	0.20
20	3.98	3.24	3.72	2.64	2.51	2.94	3.45	3.24	3.63	2.72	3.21	0.50
21	2.15	3.02	5.31	2.52	4.76	3.20	4.52	3.02	2.54	3.00	3.40	1.07
22	3.48	3.45	3.65	2.72	4.09	3.33	2.36	3.52	3.48	2.99	3.31	0.50
23	1.87	1.36	1.28	2.03	1.71	2.42	1.75	1.33	2.00	1.33	1.71	0.38
24	0.99	1.22	1.17	1.45	1.09	0.89	1.22	1.32	1.01	1.52	1.19	0.20
25	3.50	3.26	2.09	1.82	1.82	1.92	1.99	2.36	2.86	2.66	2.43	0.61
26	6.41	5.48	4.48	4.16	2.95	5.09	6.45	5.56	4.99	5.02	5.06	1.04
27	3.79	2.85	2.99	1.57	1.30	1.33	1.57	2.03	2.12	2.58	2.21	0.83
28	2.10	2.24	1.89	1.51	1.48	1.17	1.54	2.21	2.00	1.85	1.80	0.36
29	1.58	1.17	2.16	1.20	2.30	1.92	1.73	2.03	2.33	2.11	1.85	0.42
30	2.99	3.89	2.46	1.03	1.37	1.99	2.00	3.22	1.24	1.00	2.12	1.00
31	1.65	1.73	1.76	1.31	1.31	1.99	1.68	1.52	1.24	1.24	1.54	0.26
32	2.15	2.08	2.69	1.66	1.49	2.27	2.03	1.99	2.15	2.10	2.06	0.33
33	2.03	2.25	2.01	0.84	1.17	1.99	1.52	1.44	2.00	2.04	1.73	0.46
34	3.05	3.83	2.33	1.08	0.95	1.71	1.85	1.20	1.59	1.25	1.88	0.93
35	1.53	1.71	1.28	1.45	1.40	1.40	1.45	1.28	1.73	1.33	1.46	0.16
36	0.91	1.17	0.96	0.50	1.14	0.87	1.00	0.83	0.75	1.00	0.91	0.20
37	1.46	0.98	0.93	1.03	0.98	0.87	1.03	1.00	1.45	1.00	1.07	0.21
38	0.52	1.55	1.44	1.94	2.56	1.49	1.25	1.03	1.55	1.50	1.48	0.53
39	1.37	1.59	1.82	2.34	1.54	1.85	1.86	1.99	2.37	1.87	1.86	0.32
40	1.56	2.50	2.82	1.10	0.84	0.98	1.11	0.56	0.75	1.00	1.32	0.76
41	1.46	1.91	1.86	2.35	1.54	1.85	1.33	1.26	1.11	1.37	1.60	0.38
42	1.86	0.92	1.36	0.66	0.93	0.93	0.99	0.75	1.24	0.97	1.06	0.35
43	0.95	0.90	1.25	1.09	0.67	0.87	1.00	1.00	1.07	0.97	0.98	0.15
44	1.00	0.79	1.04	0.79	1.73	0.51	0.75	0.86	1.03	0.97	0.95	0.32
45	1.44	1.14	1.05	1.07	1.05	0.59	0.69	0.85	1.11	0.97	1.00	0.24
46	1.46	1.49	0.98	0.85	1.08	1.01	1.33	1.00	1.45	1.30	1.19	0.24
47	0.75	0.97	0.97	0.76	0.66	0.56	0.65	0.85	0.48	0.75	0.74	0.16
										Mean	*2.13*	*0.51*

Table C-2b the border experimental data of subject NJ at condition 50 lux illumination.

No.	1	2	3	4	5	6	7	8	9	10	Average	Stnd Div
1	8.05	9.21	8.99	8.33	9.02	8.52	9.12	8.33	9.01	8.96	8.75	0.41
2	15.69	17.09	18.87	16.25	18.00	15.33	17.08	14.25	15.23	17.24	16.50	1.41
3	7.51	10.36	9.94	10.36	9.94	8.25	10.23	9.52	9.24	10.59	9.59	1.00
4	9.96	9.37	10.46	9.87	10.00	9.37	9.25	9.75	10.45	9.66	9.81	0.42
5	11.11	13.63	15.21	13.63	14.75	11.11	12.33	13.23	14.66	11.25	13.09	1.57
6	11.80	11.32	15.22	11.52	10.25	12.33	11.25	11.63	11.97	12.33	11.96	1.29
7	6.06	7.26	7.24	7.29	6.06	6.00	7.56	7.52	6.02	7.12	6.81	0.68
8	4.83	5.59	5.78	4.86	5.55	4.97	5.02	5.63	4.89	5.24	5.23	0.37
9	14.37	16.57	15.01	15.00	14.85	15.43	16.02	15.63	15.22	15.45	15.36	0.62
10	15.17	16.78	17.20	16.66	15.45	16.24	17.01	16.54	15.99	16.55	16.36	0.66
11	14.36	13.03	13.98	14.52	13.85	13.25	14.74	13.56	14.78	15.25	14.13	0.72
12	8.69	10.89	10.21	9.52	10.13	10.85	9.55	9.55	10.27	8.95	9.86	0.74
13	4.82	7.69	5.32	5.63	7.86	7.52	6.85	7.52	7.24	6.42	6.69	1.09
14	4.99	4.04	5.16	4.99	4.58	5.24	4.85	5.24	5.26	4.12	4.85	0.45
15	15.27	12.55	12.65	13.32	14.25	12.33	12.35	15.24	14.24	13.23	13.54	1.14
16	14.91	12.01	16.63	13.23	12.27	15.24	14.91	14.25	12.03	15.33	14.08	1.61
17	7.45	8.31	12.48	8.03	10.25	7.13	8.26	8.23	9.33	10.23	8.97	1.63
18	7.47	6.44	6.44	6.86	7.75	6.56	7.12	6.22	7.02	6.86	6.87	0.48
19	5.13	6.09	4.45	5.63	4.52	4.45	5.24	6.86	4.24	5.63	5.22	0.84
20	7.22	8.86	10.85	9.24	8.54	7.13	7.77	8.56	7.25	10.25	8.57	1.28
21	11.90	12.40	14.74	12.56	11.97	14.52	13.24	14.25	13.22	12.22	13.10	1.07
22	7.75	11.64	10.58	11.75	10.55	11.24	8.24	7.22	10.24	12.33	10.15	1.80
23	6.51	8.28	7.95	7.69	8.79	9.86	6.33	8.22	7.22	7.24	7.81	1.06
24	8.05	5.78	6.63	5.24	6.91	5.09	5.86	8.21	6.44	6.23	6.44	1.06
25	15.69	13.25	13.93	13.25	14.25	13.23	14.59	13.22	13.27	14.53	13.92	0.84
26	10.89	14.45	13.81	14.45	15.33	14.23	16.25	15.11	14.21	13.23	14.20	1.43
27	7.44	10.63	9.32	7.17	7.34	9.24	10.02	11.21	7.26	7.25	8.69	1.58
28	5.43	6.19	6.34	5.45	6.58	6.23	6.33	5.44	6.22	5.89	6.01	0.43
29	6.62	5.74	5.93	4.54	3.31	3.12	6.52	5.23	6.24	5.21	5.25	1.25
30	8.36	9.12	8.67	8.97	7.26	8.13	9.15	9.45	9.52	9.40	8.80	0.72
31	6.54	10.71	11.38	11.33	10.25	9.02	8.52	12.33	10.00	11.20	10.13	1.70
32	4.86	5.34	6.75	5.23	5.02	5.76	6.46	6.22	5.23	5.00	5.59	0.67
33	6.83	6.79	8.13	6.45	7.01	6.32	6.21	8.03	7.45	6.79	7.00	0.67
34	9.10	11.80	10.61	10.63	11.43	9.24	10.24	9.22	11.02	10.23	10.35	0.94
35	4.15	7.11	5.94	5.95	5.55	6.33	4.13	5.23	5.24	4.25	5.39	1.00
36	5.50	7.07	9.52	7.24	6.24	5.23	9.13	9.36	8.25	7.13	7.46	1.56
37	4.20	6.92	5.52	4.52	4.20	6.85	5.12	5.12	5.55	4.99	5.30	0.96
38	4.08	4.41	4.59	4.12	4.44	4.85	4.33	4.00	4.12	5.00	4.39	0.34
39	4.36	4.38	4.21	4.33	4.22	4.55	4.00	4.12	4.13	4.99	4.33	0.28
40	4.27	6.57	6.80	6.24	6.23	6.52	5.25	6.23	5.75	6.25	6.01	0.75
41	3.17	5.22	2.38	5.20	2.31	2.33	3.25	3.23	5.20	3.22	3.55	1.21
42	4.37	3.47	5.05	4.33	3.55	6.22	4.24	5.24	3.24	5.23	4.49	0.94
43	3.94	4.04	3.03	3.25	4.13	3.23	4.02	4.58	3.25	3.23	3.67	0.53
44	1.61	1.68	2.14	1.61	1.85	2.13	1.63	2.14	2.22	1.33	1.83	0.31
45	2.65	2.51	1.88	2.67	1.86	2.51	1.25	2.13	1.25	2.24	2.10	0.53
46	1.73	2.20	1.66	1.79	2.00	1.25	1.33	1.52	1.78	1.85	1.71	0.29
47	1.74	1.69	2.26	1.75	1.23	1.54	1.89	1.55	1.24	1.23	1.61	0.33
										Mean	*8.20*	*0.91*

Table C-3a the border experimental data of subject PP at condition 5 lux illumination.

No.	1	2	3	4	5	6	7	8	9	10	Average	Stnd Div
1	5.37	5.29	6.88	4.18	4.75	4.92	5.40	6.56	6.64	8.16	5.81	1.21
2	9.17	6.67	10.1	4.66	6.15	6.74	7.44	8.69	8.89	9.21	7.77	1.70
3	3.44	3.02	4.95	2.88	3.75	3.78	4.03	4.11	4.81	5.51	4.03	0.85
4	2.51	2.74	3.27	4.03	4.63	4.86	4.86	5.78	5.85	6.05	4.46	1.29
5	4.52	5.91	6.59	7.54	7.93	8.09	8.41	6.59	4.52	5.91	6.60	1.40
6	6.91	5.36	6.98	4.04	4.56	5.05	5.46	5.80	6.07	6.58	5.68	0.98
7	7.09	4.98	6.06	2.60	2.82	4.01	5.27	2.60	2.82	4.01	4.23	1.58
8	4.56	5.17	6.08	3.32	4.30	4.37	4.43	4.51	4.70	5.27	4.67	0.73
9	7.84	9.12	7.78	2.87	4.18	4.42	2.87	4.18	4.46	2.88	5.06	2.32
10	6.05	9.21	9.02	4.83	5.25	5.84	6.05	4.83	5.25	5.25	6.16	1.62
11	1.43	2.12	2.92	3.20	3.45	3.86	4.47	5.74	3.86	2.92	3.40	1.20
12	2.82	2.93	3.07	3.77	4.26	4.39	2.82	2.93	3.77	3.07	3.38	0.61
13	2.12	3.29	4.06	2.01	2.55	2.94	3.11	3.19	3.76	3.86	3.09	0.70
14	2.36	2.90	3.54	3.24	3.91	4.03	5.23	2.36	2.90	3.54	3.40	0.86
15	3.24	3.13	2.56	7.26	6.66	6.62	7.01	7.51	7.97	7.62	5.96	2.10
16	5.72	7.07	7.37	7.73	9.20	10.7	10.7	10.9	7.07	7.37	8.39	1.85
17	4.15	4.19	3.86	3.00	3.32	3.73	3.86	4.30	4.64	3.32	3.84	0.51
18	3.53	3.90	4.02	4.25	4.32	4.49	5.86	3.90	3.53	4.02	4.18	0.67
19	4.75	5.05	4.06	2.49	2.73	3.82	3.84	2.49	2.73	3.82	3.58	0.93
20	4.55	6.37	5.01	3.82	4.18	4.58	5.45	5.76	6.66	6.78	5.32	1.05
21	10.3	9.58	9.37	9.12	8.27	6.13	8.42	6.99	6.65	6.13	8.09	1.52
22	4.54	5.81	6.37	6.47	3.57	4.02	4.54	4.13	6.37	6.47	5.23	1.18
23	3.89	4.01	3.20	2.47	3.15	3.44	3.85	4.18	4.60	5.32	3.81	0.80
24	5.46	5.64	4.75	2.28	2.31	2.62	2.88	2.31	2.62	2.88	3.38	1.35
25	9.54	8.67	7.67	5.47	5.65	6.27	6.66	8.24	10.0	6.27	7.45	1.63
26	7.19	6.15	6.56	3.25	3.94	4.41	4.44	4.60	4.72	5.17	5.04	1.23
27	3.24	4.15	4.38	4.46	5.01	5.04	5.96	4.15	4.38	5.01	4.58	0.73
28	5.14	5.04	3.97	2.34	2.81	3.30	3.54	5.14	3.97	2.81	3.81	1.03
29	2.88	2.92	3.36	3.90	4.64	4.68	5.96	4.68	3.36	3.90	4.03	0.97
30	2.46	4.42	2.68	2.87	3.24	3.49	4.12	5.29	6.02	4.12	3.87	1.16
31	4.08	5.46	5.76	6.30	6.49	7.08	7.20	5.46	4.08	5.76	5.77	1.08
32	5.68	6.25	3.30	2.25	3.32	3.42	4.45	3.42	3.32	3.32	3.87	1.23
33	3.30	3.90	4.90	3.99	4.51	4.73	4.78	4.88	5.00	4.51	4.45	0.55
34	2.45	4.06	4.15	4.47	5.01	6.21	6.21	2.45	4.06	4.15	4.32	1.28
35	3.24	3.07	3.52	2.95	4.57	4.60	4.65	4.77	5.55	5.94	4.28	1.04
36	3.64	3.14	3.58	4.05	4.32	4.44	5.34	3.64	3.14	3.58	3.89	0.67
37	5.60	5.58	5.23	2.17	2.78	2.80	3.49	3.78	4.86	3.49	3.98	1.25
38	2.85	2.95	3.43	3.50	3.59	3.69	3.96	3.43	3.50	3.59	3.45	0.33
39	2.91	2.99	3.81	3.95	3.96	4.01	4.41	2.91	2.99	3.81	3.57	0.56
40	3.74	4.93	2.44	3.07	3.20	3.22	3.29	3.60	3.62	3.75	3.49	0.64
41	1.85	2.56	2.67	2.73	2.78	3.28	3.88	2.56	2.67	2.67	2.77	0.52
42	3.41	3.60	4.13	2.36	3.88	4.42	4.42	4.13	3.60	2.36	3.63	0.75
43	4.35	4.61	4.68	2.36	3.88	4.42	4.42	4.35	4.61	2.36	4.00	0.89
44	3.71	3.32	2.61	1.65	1.67	2.34	1.67	2.34	2.37	2.49	2.42	0.69
45	1.78	1.93	2.45	2.56	2.71	3.19	3.34	1.78	1.93	1.77	2.34	0.60
46	2.09	2.20	2.25	2.25	2.43	2.79	2.85	3.15	2.09	2.20	2.43	0.37
47	2.19	2.26	1.73	1.40	1.43	1.77	2.13	2.13	2.20	2.30	1.95	0.34
										Mean	*4.44*	*1.03*

Table C-3b the border experimental data of subject PP at condition 50 lux illumination.

No.	1	2	3	4	5	6	7	8	9	10	Average	Stnd Div
1	13.79	18.42	16.55	17.49	18.64	19.89	18.24	15.24	18.22	17.24	17.37	1.78
2	20.13	23.23	24.26	24.39	27.62	24.39	23.45	24.13	27.63	25.22	24.44	2.16
3	23.62	19.93	20.97	18.42	18.46	17.24	18.92	20.24	19.24	20.29	19.73	1.75
4	19.93	19.68	20.77	17.00	20.24	19.27	21.33	20.75	19.26	17.52	19.58	1.39
5	18.92	21.99	23.57	23.23	18.44	21.99	23.15	21.54	22.26	19.52	21.46	1.85
6	7.55	10.30	10.46	7.90	9.77	8.94	10.26	9.53	8.13	7.55	9.04	1.18
7	10.03	10.94	10.19	11.13	11.84	10.66	10.64	11.17	11.94	13.93	11.25	1.13
8	7.34	9.47	9.01	9.11	10.20	8.20	8.36	10.25	9.55	7.27	8.87	1.07
9	20.73	22.97	24.25	14.32	14.87	18.24	20.22	19.25	20.00	19.24	19.41	3.11
10	25.54	27.15	29.34	25.38	25.43	25.38	27.26	25.24	24.22	23.27	25.82	1.71
11	12.01	14.21	13.09	14.21	15.83	14.43	15.22	15.87	16.51	13.27	14.46	1.42
12	12.70	11.69	10.91	7.85	8.26	10.75	11.69	10.24	11.69	10.91	10.67	1.54
13	7.19	7.99	10.48	9.25	10.73	11.85	11.51	10.14	10.25	9.26	9.87	1.47
14	8.32	7.19	7.59	6.81	5.96	7.15	7.27	8.27	7.00	7.22	7.28	0.69
15	13.51	12.65	12.81	16.39	17.23	16.55	19.59	16.50	17.25	18.27	16.08	2.34
16	18.80	17.28	11.33	16.67	11.97	20.90	18.69	19.49	17.54	18.26	17.09	3.11
17	13.83	13.40	13.22	8.82	7.30	7.14	12.47	13.25	12.54	11.25	11.32	2.60
18	10.14	11.23	9.93	12.32	9.59	10.75	10.13	9.23	10.46	11.33	10.51	0.92
19	4.91	4.55	6.19	8.92	8.62	8.57	6.52	5.22	6.23	4.24	6.40	1.76
20	19.49	17.20	21.83	15.78	19.02	15.34	21.61	15.60	19.49	21.61	18.70	2.58
21	20.91	19.27	20.82	23.75	23.84	25.03	21.65	19.56	20.78	19.81	21.54	2.00
22	16.17	18.01	18.68	15.17	19.59	15.20	16.26	17.48	16.17	18.56	17.13	1.55
23	6.37	6.55	8.07	7.02	8.93	10.54	11.82	10.43	10.23	10.60	9.05	1.95
24	8.53	11.09	10.36	10.69	8.59	8.89	10.46	9.37	10.27	8.63	9.69	0.99
25	15.20	14.93	14.42	13.18	14.55	16.37	15.82	14.53	15.87	16.33	15.12	1.00
26	20.50	15.66	20.82	15.09	16.55	16.09	17.05	18.76	16.24	20.62	17.74	2.23
27	10.89	12.46	10.89	12.46	14.08	12.49	13.98	15.41	10.22	11.26	12.41	1.67
28	8.20	6.55	5.14	9.41	9.27	9.86	11.11	10.01	9.45	9.96	8.90	1.79
29	10.01	9.45	9.96	10.24	9.27	10.24	8.24	11.03	8.59	9.63	9.66	0.82
30	17.48	16.95	15.27	17.20	15.13	16.11	17.87	17.87	17.93	16.81	16.86	1.04
31	15.93	14.05	13.55	17.73	13.14	14.57	11.02	10.25	12.33	14.25	13.68	2.20
32	4.04	3.79	3.68	7.76	5.18	6.39	5.45	4.55	5.63	6.32	5.28	1.31
33	12.97	12.17	11.60	11.89	10.33	8.23	8.36	7.33	8.27	8.22	9.93	2.08
34	11.41	9.57	10.78	12.30	10.55	10.14	9.70	10.33	11.25	10.87	10.69	0.83
35	10.55	10.14	9.70	8.26	7.55	8.30	10.26	8.23	9.24	10.25	9.25	1.08
36	5.30	4.59	4.59	6.25	6.05	5.63	6.25	5.55	5.43	6.33	5.60	0.64
37	6.05	4.41	6.66	7.26	9.26	9.26	10.01	7.26	5.55	6.25	7.20	1.81
38	5.61	5.29	4.13	4.01	3.17	3.62	4.53	5.63	7.26	5.03	4.83	1.20
39	4.01	3.17	3.62	5.65	8.27	6.25	4.29	6.27	5.63	4.27	5.14	1.55
40	9.82	9.44	9.49	10.28	10.62	7.26	9.27	8.51	7.60	8.03	9.03	1.14
41	4.77	6.74	7.63	5.96	5.87	6.61	8.88	7.61	8.26	7.21	6.95	1.22
42	5.22	2.39	2.90	2.63	3.53	4.11	2.36	3.25	2.53	2.89	3.18	0.90
43	4.49	4.13	5.30	4.60	7.82	7.65	5.60	5.51	4.56	4.44	5.41	1.32
44	4.07	5.72	5.14	4.67	4.38	5.47	7.09	5.62	4.90	4.63	5.17	0.86
45	2.82	2.78	3.45	3.56	2.57	3.00	2.76	2.53	3.44	3.10	3.00	0.38
46	3.33	3.48	2.90	3.00	2.91	4.14	3.84	4.36	4.02	3.20	3.52	0.54
47	2.94	2.86	2.88	2.87	3.00	2.47	3.27	2.75	1.96	2.65	2.76	0.35
										Mean	*11.66*	*1.49*

Table C-4a the border experimental data of subject PS at condition 5 lux illumination.

No.	1	2	3	4	5	6	7	8	9	10	Average	Stnd Div
1	1.25	1.29	1.33	1.53	1.33	1.63	1.86	1.29	1.25	1.29	1.40	0.20
2	1.62	1.77	1.77	1.33	1.99	1.85	1.77	1.62	1.77	1.33	1.68	0.21
3	0.88	1.38	1.43	1.32	1.41	1.24	1.22	1.45	1.32	1.00	1.27	0.19
4	1.49	1.19	1.49	1.13	1.24	1.33	1.52	1.65	1.62	1.45	1.41	0.18
5	1.30	2.05	1.93	2.63	2.01	1.99	1.76	1.66	1.57	2.01	1.89	0.36
6	1.04	1.33	1.76	1.04	1.33	1.56	1.34	1.22	1.05	1.23	1.29	0.23
7	0.77	0.89	1.06	0.86	0.57	0.79	0.68	0.76	1.05	1.13	0.85	0.18
8	1.07	0.91	1.01	0.45	0.52	0.68	0.76	0.45	0.46	0.46	0.68	0.25
9	1.37	0.92	1.19	1.65	1.38	1.33	1.19	0.99	0.90	1.37	1.23	0.24
10	1.09	1.30	1.46	1.57	1.45	2.65	1.57	1.22	2.02	2.25	1.66	0.50
11	1.62	1.49	1.30	2.37	2.15	2.85	1.55	1.90	1.66	1.67	1.86	0.47
12	0.80	1.14	1.14	1.45	1.32	1.14	0.90	0.99	1.25	0.76	1.09	0.23
13	0.48	0.78	0.75	0.49	0.42	0.57	0.76	0.45	0.66	0.87	0.62	0.16
14	0.87	0.94	1.06	0.45	0.65	0.66	0.54	0.37	0.85	0.45	0.68	0.24
15	1.87	2.08	2.35	2.37	2.46	1.99	2.42	2.09	2.33	2.02	2.20	0.21
16	1.72	1.83	1.83	2.03	2.42	1.88	1.99	1.87	2.01	1.86	1.94	0.19
17	1.12	1.22	1.32	1.55	1.33	1.25	1.55	1.33	1.99	1.37	1.40	0.24
18	1.20	0.92	1.20	0.99	0.87	0.76	0.96	0.63	0.87	1.00	0.94	0.18
19	0.47	0.76	0.88	0.96	0.55	0.56	0.77	0.86	0.76	0.63	0.72	0.16
20	0.99	1.30	1.21	1.32	1.25	1.10	0.99	1.36	1.15	1.32	1.20	0.14
21	1.42	1.56	1.51	1.66	1.86	2.05	2.15	1.99	1.76	2.15	1.81	0.27
22	1.37	1.29	1.58	1.36	1.55	1.96	1.32	1.29	1.58	1.36	1.47	0.21
23	1.32	1.14	1.06	1.02	0.99	1.33	0.75	1.14	1.02	0.99	1.08	0.17
24	1.02	0.99	0.69	1.02	1.25	0.63	0.97	1.33	1.01	0.76	0.97	0.22
25	1.44	1.89	2.03	1.76	1.74	2.01	1.44	1.99	1.85	1.32	1.75	0.26
26	0.89	1.57	1.42	1.66	1.75	1.32	0.99	1.15	1.00	1.23	1.30	0.30
27	1.06	0.80	1.16	1.23	1.02	1.42	0.86	1.12	1.05	1.21	1.09	0.18
28	0.77	1.09	0.96	0.76	0.86	1.02	0.87	0.96	1.03	0.86	0.92	0.11
29	0.77	0.64	0.48	0.90	0.96	1.07	0.64	1.00	1.02	0.75	0.82	0.20
30	2.07	1.68	1.65	1.75	2.13	1.72	1.65	1.68	2.00	1.32	1.77	0.24
31	0.92	1.01	0.84	0.87	0.99	1.00	0.89	0.91	1.03	0.76	0.92	0.09
32	1.28	1.26	1.18	1.00	1.13	0.99	1.02	1.00	0.76	0.99	1.06	0.16
33	0.82	0.76	1.10	0.89	1.12	1.00	0.89	1.20	1.21	1.03	1.00	0.16
34	0.82	0.93	0.93	0.86	0.76	0.87	1.00	0.99	1.21	1.05	0.94	0.13
35	1.14	1.38	1.21	1.40	1.45	1.32	1.10	1.23	1.66	1.32	1.32	0.16
36	1.21	1.21	0.75	0.79	1.35	1.63	1.33	1.86	1.63	2.02	1.38	0.42
37	0.53	0.82	0.66	0.53	0.85	0.76	0.65	0.69	0.75	0.87	0.71	0.12
38	1.10	1.17	0.89	1.15	1.24	1.03	0.99	0.89	0.97	1.10	1.05	0.12
39	0.61	0.67	0.66	0.68	0.61	0.71	0.69	0.68	0.65	0.99	0.69	0.11
40	1.36	1.33	1.48	1.32	1.10	0.63	0.66	0.75	0.45	0.69	0.98	0.38
41	0.66	0.76	0.66	0.66	0.45	0.76	0.76	0.66	0.45	0.76	0.66	0.12
42	0.90	0.98	0.86	0.76	0.90	0.98	0.42	0.58	0.77	0.46	0.76	0.21
43	0.42	0.42	0.42	0.43	0.48	0.40	0.58	0.37	0.65	0.58	0.47	0.09
44	0.29	0.23	0.22	0.33	0.67	0.25	0.23	0.33	0.33	0.23	0.31	0.13
45	0.54	0.74	0.44	0.43	0.74	0.63	0.47	0.27	0.66	0.57	0.55	0.15
46	0.34	0.43	0.42	0.37	0.42	0.43	0.37	0.33	0.43	0.40	0.39	0.04
47	0.37	0.31	0.34	0.33	0.32	0.21	0.29	0.32	0.24	0.37	0.31	0.05
										Mean	*1.12*	*0.20*

Table C-4b the border experimental data of subject PS at condition 50 lux illumination.

No.	1	2	3	4	5	6	7	8	9	10	Average	Stnd Div
1	12.59	12.10	13.93	14.33	12.33	11.33	13.66	12.33	13.65	12.55	12.88	0.96
2	11.78	14.12	13.29	11.32	10.23	12.33	14.33	13.33	11.23	10.23	12.22	1.51
3	10.57	13.00	15.32	16.33	15.32	16.23	10.25	13.67	15.25	13.23	13.92	2.18
4	12.20	11.85	12.89	13.00	13.25	13.22	15.32	14.25	15.33	13.25	13.46	1.18
5	17.06	17.48	18.42	16.33	18.23	17.23	12.34	15.67	16.59	17.26	16.66	1.73
6	12.20	8.14	9.29	11.29	12.33	11.56	10.89	13.59	9.33	10.23	10.88	1.65
7	12.20	10.11	11.47	10.11	9.87	12.33	12.65	10.67	11.23	10.23	11.09	1.04
8	8.96	10.06	10.56	7.96	10.23	7.33	10.65	8.66	7.25	8.66	9.03	1.29
9	10.89	11.53	9.93	10.33	11.67	12.56	13.23	10.32	12.66	10.25	11.34	1.17
10	17.09	13.66	13.92	18.57	13.53	14.33	16.34	18.66	17.25	18.33	16.17	2.12
11	11.36	10.39	10.81	12.33	11.15	11.66	13.23	12.33	10.37	11.35	11.50	0.91
12	12.08	11.97	13.32	11.33	13.37	12.33	11.26	10.97	11.33	12.25	12.02	0.84
13	10.54	10.13	10.62	9.87	10.23	9.57	10.35	9.86	10.66	10.35	10.22	0.36
14	5.71	5.61	6.35	5.66	6.36	7.33	6.33	4.23	4.99	5.23	5.78	0.87
15	12.33	14.90	13.45	15.23	15.33	14.99	13.55	15.63	12.75	13.97	14.21	1.16
16	20.69	18.33	21.36	16.86	22.34	21.33	20.33	15.66	16.33	17.66	19.09	2.40
17	9.89	11.44	12.33	13.33	11.23	12.65	13.00	11.32	9.90	12.37	11.75	1.20
18	12.38	10.11	10.01	10.37	9.86	10.35	11.57	12.66	10.55	11.67	10.95	1.03
19	6.62	6.19	7.57	6.33	5.97	6.89	7.33	6.46	6.89	7.25	6.75	0.53
20	10.37	14.48	12.97	11.36	14.53	12.33	11.25	10.97	11.66	14.86	12.48	1.64
21	17.71	21.55	22.65	23.67	22.55	21.55	18.66	24.33	22.65	23.67	21.90	2.16
22	12.13	12.37	10.76	13.33	16.23	12.37	13.33	12.67	13.23	10.33	12.67	1.61
23	11.31	12.08	13.34	10.80	10.19	12.12	12.37	11.54	12.56	10.67	11.70	0.97
24	9.09	8.33	8.96	8.33	9.09	7.57	7.97	8.37	9.03	8.76	8.55	0.52
25	14.11	15.93	16.37	16.25	15.26	16.33	15.33	15.65	14.32	16.32	15.59	0.83
26	15.66	10.25	11.25	15.33	10.67	11.52	11.11	12.33	15.23	13.23	12.66	2.07
27	11.88	11.13	11.38	10.34	10.00	11.35	10.33	10.56	9.67	10.33	10.70	0.70
28	8.93	10.02	8.24	8.33	8.32	10.54	10.03	8.67	9.27	10.52	9.29	0.92
29	12.92	12.73	12.34	11.29	13.11	12.87	12.33	13.33	13.67	11.23	12.58	0.81
30	10.26	11.02	11.16	10.33	10.32	9.66	10.33	11.67	9.67	10.67	10.51	0.64
31	12.03	11.86	11.21	13.70	10.33	10.66	12.65	11.66	10.66	12.66	11.74	1.06
32	9.15	8.73	9.61	8.65	7.70	8.25	7.37	8.33	9.67	10.23	8.77	0.90
33	11.56	12.71	13.92	13.33	11.25	12.33	13.22	11.25	13.33	10.33	12.32	1.17
34	8.26	6.35	9.14	6.24	6.46	5.67	6.33	7.27	6.63	6.32	6.87	1.06
35	5.64	9.59	8.82	5.63	7.65	6.33	7.66	6.67	6.89	7.65	7.25	1.29
36	9.02	8.38	9.62	8.25	8.67	6.65	7.43	9.65	7.66	8.64	8.40	0.95
37	7.33	7.33	7.67	6.53	6.32	5.24	6.33	5.62	6.58	6.10	6.50	0.77
38	8.88	11.62	13.04	12.37	13.01	12.87	11.69	8.65	9.37	8.76	11.03	1.89
39	6.45	6.28	5.85	5.64	5.69	6.32	4.37	5.70	5.66	5.97	5.79	0.59
40	3.63	7.05	7.76	3.65	6.67	7.67	6.21	3.65	4.67	4.79	5.57	1.68
41	3.62	4.42	5.13	6.53	3.26	3.63	4.63	3.65	4.26	3.66	4.28	0.98
42	4.55	5.20	4.27	4.67	6.33	4.27	5.33	5.21	4.27	3.63	4.77	0.76
43	3.46	3.10	3.46	3.86	3.06	4.96	2.66	3.65	2.64	3.66	3.45	0.68
44	2.46	3.86	4.01	3.56	4.22	2.66	3.66	4.22	3.65	2.42	3.47	0.70
45	7.19	5.76	6.58	6.32	5.26	6.33	7.24	6.45	7.64	5.66	6.44	0.76
46	3.30	2.32	2.01	2.01	2.66	3.67	2.11	2.67	2.94	3.22	2.69	0.59
47	2.37	2.85	3.08	2.15	2.37	2.66	2.37	3.33	2.32	2.10	2.56	0.41
										Mean	*10.22*	*1.13*

Table C-5a the border experimental data of subject WU at condition 5 lux illumination.

No.	1	2	3	4	5	6	7	8	9	10	Average	Stnd Div
1	3.37	6.38	9.94	5.01	5.11	5.41	4.44	3.75	4.11	4.08	5.16	1.90
2	9.38	11.7	9.66	9.75	9.44	9.41	10.1	9.74	8.04	8.04	9.53	1.04
3	6.82	4.19	4.99	5.08	4.11	6.41	5.41	4.75	5.30	5.00	5.21	0.86
4	8.76	7.14	5.83	6.79	7.11	7.19	6.57	9.46	9.08	6.44	7.44	1.23
5	6.27	5.64	8.38	6.26	6.42	6.74	7.08	7.55	8.08	6.41	6.88	0.88
6	3.83	4.71	3.72	4.11	4.11	3.75	3.95	3.57	4.99	4.75	4.15	0.49
7	2.39	4.12	3.08	2.89	3.09	2.67	3.41	3.75	3.54	3.41	3.24	0.52
8	3.13	2.63	2.59	2.67	2.75	3.00	2.86	2.44	2.79	3.08	2.79	0.22
9	7.32	6.97	7.15	6.75	6.63	6.08	7.11	7.75	7.11	6.46	6.93	0.47
10	6.27	7.71	7.11	6.78	7.11	5.98	6.08	5.76	6.11	6.41	6.53	0.62
11	3.41	6.84	3.56	3.56	4.75	3.78	3.12	4.08	3.41	3.85	4.04	1.08
12	2.65	3.52	3.35	2.62	2.75	3.08	3.33	3.08	3.11	2.63	3.01	0.33
13	2.91	3.08	2.73	2.93	2.73	3.08	2.71	2.67	2.75	3.00	2.86	0.16
14	2.49	2.00	2.23	2.04	2.11	2.29	2.34	2.32	2.18	2.37	2.24	0.16
15	7.76	9.45	8.06	8.08	7.44	9.08	7.44	8.44	8.07	7.11	8.09	0.74
16	5.26	6.24	5.94	5.75	6.08	5.75	6.00	6.42	5.75	5.32	5.85	0.37
17	4.78	5.31	4.47	4.78	5.31	4.41	4.99	5.11	4.75	4.42	4.83	0.34
18	2.12	2.71	2.89	2.41	2.75	2.44	2.30	2.34	2.42	2.71	2.51	0.24
19	1.98	2.64	2.85	1.98	2.61	2.74	2.63	2.67	1.99	2.19	2.43	0.35
20	7.75	9.87	7.81	7.82	8.11	8.11	7.78	7.07	6.78	7.44	7.85	0.83
21	5.74	7.28	8.83	5.75	6.08	5.75	5.74	6.08	6.41	6.67	6.43	0.98
22	6.32	4.80	5.57	5.08	5.41	5.74	5.11	5.75	4.75	5.08	5.36	0.49
23	3.41	4.11	4.11	3.41	3.08	3.41	3.33	3.41	3.41	3.75	3.54	0.34
24	2.93	3.13	1.99	3.08	3.00	2.08	2.42	2.88	3.12	3.42	2.81	0.48
25	4.70	6.86	5.40	5.41	5.30	4.78	6.08	5.08	5.44	5.39	5.44	0.63
26	4.18	3.17	4.85	3.41	4.75	4.15	4.42	3.75	3.75	3.66	4.01	0.56
27	4.18	2.95	4.15	3.41	3.33	4.11	3.75	4.00	3.41	3.75	3.71	0.42
28	2.30	2.92	2.41	2.99	2.41	2.08	2.40	2.75	2.59	2.67	2.55	0.29
29	4.42	4.52	4.74	4.42	4.52	4.74	4.37	3.67	3.67	4.75	4.38	0.40
30	3.51	3.37	3.37	3.37	3.51	3.67	3.30	3.82	3.75	3.08	3.47	0.23
31	3.04	2.98	4.97	3.75	4.11	4.97	4.42	3.75	4.11	4.41	4.05	0.69
32	3.22	3.31	3.11	3.31	3.22	3.41	3.42	3.33	2.71	3.42	3.25	0.21
33	3.79	4.46	3.97	4.00	4.41	4.08	3.75	4.67	3.44	4.11	4.07	0.37
34	3.30	3.44	2.94	2.94	3.44	3.44	3.30	2.88	3.41	3.08	3.22	0.23
35	3.24	3.64	2.85	3.24	3.64	3.24	3.41	2.84	2.75	0.78	2.96	0.83
36	2.85	3.53	3.10	2.85	3.21	3.42	3.42	3.08	2.86	3.00	3.13	0.26
37	3.41	3.67	2.99	3.41	3.62	3.67	3.66	3.12	2.93	3.11	3.36	0.30
38	3.55	3.41	3.45	3.55	3.41	3.45	3.55	3.75	3.08	3.42	3.46	0.17
39	1.95	2.36	1.56	1.95	2.36	1.56	1.85	2.11	1.99	2.08	1.98	0.28
40	2.54	2.29	2.36	2.36	2.54	2.93	2.42	2.42	2.30	2.99	2.51	0.25
41	2.32	3.39	3.13	3.11	3.42	3.11	2.75	3.42	2.09	3.42	3.01	0.48
42	2.30	1.94	1.91	2.30	1.78	2.08	2.42	1.75	1.42	1.41	1.93	0.35
43	1.75	2.22	2.33	2.22	2.33	1.75	1.95	2.01	1.75	2.08	2.04	0.24
44	1.91	2.38	2.05	2.04	1.71	2.41	2.30	1.67	2.08	2.11	2.07	0.25
45	1.75	1.37	1.80	1.38	1.72	1.74	1.37	1.44	1.40	1.75	1.57	0.19
46	1.43	1.03	1.70	1.08	1.04	1.29	1.42	1.03	1.67	1.67	1.34	0.28
47	1.31	1.22	1.10	1.11	1.29	1.34	1.08	1.00	1.11	1.04	1.16	0.12
										Mean	*4.01*	*0.49*

Table C-5b the border experimental data of subject WU at condition 50 lux illumination.

No.	1	2	3	4	5	6	7	8	9	10	Average	Stnd Div
1	32.30	28.30	28.52	28.33	29.33	30.22	29.33	28.23	29.25	30.13	29.39	1.25
2	30.12	31.17	32.37	31.25	30.25	30.23	29.20	29.33	30.22	31.25	30.54	0.97
3	17.91	24.54	19.34	20.22	19.24	20.33	21.33	20.25	21.33	20.22	20.47	1.75
4	13.24	23.70	21.22	13.25	20.33	21.33	18.33	19.24	20.23	21.33	19.22	3.45
5	22.62	25.50	24.08	22.33	23.52	24.25	22.33	21.33	25.22	26.24	23.74	1.60
6	17.35	17.38	12.04	17.25	12.33	12.96	16.33	15.24	16.22	17.25	15.44	2.18
7	9.25	10.80	11.76	9.34	10.99	11.00	10.26	11.24	9.26	9.33	10.32	0.96
8	9.14	10.46	9.58	9.14	10.46	11.24	10.65	9.33	12.00	10.23	10.22	0.95
9	18.49	24.44	25.35	23.20	19.20	23.23	23.55	21.37	20.22	19.25	21.83	2.44
10	32.89	36.54	36.74	36.50	35.23	32.10	32.25	36.27	32.22	36.24	34.70	2.06
11	16.33	17.03	14.33	17.25	16.24	14.23	15.24	14.24	17.23	18.24	16.04	1.45
12	13.20	15.31	15.81	15.24	14.27	15.24	13.24	15.33	16.33	13.23	14.72	1.15
13	12.17	11.44	12.55	11.25	12.33	11.25	12.33	11.03	12.22	12.24	11.88	0.56
14	4.38	4.70	5.24	5.63	4.26	5.96	4.33	5.23	4.25	5.22	4.92	0.62
15	26.64	23.97	23.90	26.33	24.33	23.24	23.24	24.22	26.32	22.24	24.44	1.50
16	20.97	23.64	23.64	23.22	21.23	22.27	21.33	23.33	21.23	23.22	22.41	1.12
17	14.16	12.48	14.72	13.20	12.30	13.33	14.52	13.24	13.20	12.00	13.32	0.92
18	7.11	9.29	10.53	10.25	9.33	7.85	9.33	8.65	9.33	10.25	9.19	1.08
19	7.22	7.89	9.26	8.20	9.12	7.78	8.24	7.51	8.50	9.10	8.28	0.71
20	29.13	29.13	27.19	29.33	29.00	27.57	29.33	27.55	27.25	29.12	28.46	0.93
21	20.55	26.50	23.06	26.33	23.45	21.33	20.33	26.33	25.33	26.24	23.94	2.53
22	18.07	18.39	19.27	19.24	18.25	19.33	18.24	17.25	18.32	19.04	18.54	0.67
23	6.81	7.69	12.83	8.02	7.99	9.33	10.24	12.23	10.22	6.25	9.16	2.21
24	6.41	8.68	9.75	9.75	8.68	6.41	8.68	8.23	9.13	8.24	8.39	1.17
25	13.56	15.24	17.16	16.33	13.56	15.24	15.24	17.24	16.22	15.13	15.49	1.29
26	15.06	13.24	16.05	15.24	16.24	13.22	14.25	15.24	16.24	15.26	15.00	1.11
27	16.25	14.47	15.31	15.31	14.25	14.13	15.20	14.20	15.32	14.25	14.87	0.71
28	11.16	9.79	9.18	11.16	9.86	9.10	10.64	10.65	11.25	10.24	10.30	0.80
29	13.93	12.63	12.28	12.33	12.28	13.24	10.27	13.26	12.24	13.27	12.57	1.00
30	17.59	16.50	17.37	16.33	17.37	16.33	15.22	17.97	16.27	16.33	16.73	0.82
31	13.96	14.12	14.68	14.24	13.24	12.33	14.52	15.33	12.23	13.26	13.79	1.01
32	7.47	8.87	9.13	7.47	8.87	9.12	8.27	9.24	7.76	8.63	8.48	0.69
33	10.26	10.55	11.19	11.24	10.27	11.33	9.27	12.36	10.32	9.24	10.60	0.96
34	9.64	7.93	9.81	6.99	7.24	9.24	7.27	9.13	7.13	8.13	8.25	1.11
35	10.39	9.81	9.27	9.81	10.36	9.33	9.47	10.23	10.26	9.33	9.83	0.46
36	4.97	9.27	8.22	4.24	5.24	6.33	4.25	7.22	8.24	5.40	6.34	1.80
37	8.01	8.04	6.73	8.24	6.22	7.33	6.24	7.25	8.10	6.79	7.29	0.78
38	9.45	7.40	7.69	9.53	9.15	7.52	8.26	7.37	9.21	8.13	8.37	0.88
39	7.32	6.71	7.61	7.23	6.86	7.37	6.49	7.23	7.46	6.59	7.09	0.39
40	8.59	9.59	9.66	9.45	8.75	9.65	8.25	8.97	8.45	9.42	9.08	0.54
41	7.46	8.73	8.25	6.24	7.63	8.10	6.74	8.80	7.13	8.77	7.78	0.90
42	4.37	5.64	5.54	5.97	5.54	5.64	4.37	5.87	6.52	4.43	5.39	0.75
43	5.92	6.11	6.72	6.11	5.99	6.24	5.25	6.26	6.05	6.24	6.09	0.37
44	5.03	5.75	4.85	5.69	4.97	5.23	4.26	5.15	4.30	5.46	5.07	0.51
45	4.22	4.33	4.48	4.37	4.48	4.33	4.22	6.33	5.26	4.33	4.64	0.67
46	4.15	4.20	3.83	4.15	4.20	3.67	5.33	3.11	4.24	4.06	4.09	0.56
47	4.16	4.39	5.59	4.00	5.27	4.13	3.23	4.16	4.65	3.85	4.34	0.68
										Mean	*13.64*	*1.13*

Table C-6a the border experimental data of subject YT at condition 5 lux illumination.

No.	1	2	3	4	5	6	7	8	9	10	Average	Stnd Div
1	1.16	1.65	1.25	1.33	1.02	1.42	1.29	1.25	1.38	1.33	1.31	0.17
2	2.08	2.19	2.50	2.19	2.19	2.50	2.12	2.24	2.19	2.35	2.26	0.15
3	1.13	1.09	1.13	1.38	1.30	1.13	1.33	1.09	1.01	1.38	1.20	0.14
4	1.24	0.99	0.94	0.99	0.94	1.10	0.99	1.01	0.95	1.11	1.03	0.10
5	2.48	1.85	2.25	2.09	2.05	2.64	2.09	2.40	2.25	1.93	2.20	0.25
6	1.15	1.17	1.01	1.07	0.88	1.23	1.17	1.12	1.09	1.33	1.12	0.12
7	0.71	0.87	0.85	0.89	0.81	0.89	0.90	0.89	0.85	0.83	0.85	0.06
8	0.99	0.89	0.88	0.99	1.01	1.00	1.00	0.99	1.00	1.00	0.97	0.05
9	1.42	1.28	1.42	1.33	1.33	1.14	1.23	1.11	1.33	1.13	1.27	0.11
10	2.35	2.81	2.86	2.24	2.81	2.08	2.00	2.03	2.14	2.31	2.36	0.34
11	1.75	1.43	1.30	1.46	1.43	1.44	1.41	1.24	1.24	1.35	1.41	0.15
12	0.96	1.01	1.03	0.96	0.96	1.37	1.24	1.24	1.24	1.24	1.12	0.15
13	0.96	0.94	0.96	0.96	0.89	0.95	0.99	0.99	0.99	0.90	0.95	0.03
14	0.81	0.83	0.78	0.83	0.80	0.81	0.77	0.83	0.85	0.87	0.82	0.03
15	1.98	1.28	1.33	1.49	1.55	1.44	1.17	1.01	1.17	1.07	1.35	0.28
16	2.78	2.59	2.82	2.48	2.44	2.47	2.36	2.46	2.21	2.45	2.51	0.18
17	1.25	1.37	1.32	1.30	1.22	1.24	1.33	1.24	1.24	1.33	1.28	0.05
18	1.03	1.05	1.01	1.05	1.05	1.03	1.05	1.01	1.01	1.02	1.03	0.02
19	0.82	0.75	1.04	0.95	0.82	0.82	0.82	0.90	0.90	0.82	0.86	0.08
20	1.17	1.08	1.08	1.04	1.17	1.43	1.38	1.25	1.21	1.25	1.21	0.13
21	2.56	1.60	1.74	1.74	1.60	1.51	1.37	1.74	1.56	1.88	1.73	0.33
22	1.61	1.64	1.67	1.34	1.61	1.42	1.61	1.64	1.34	1.42	1.53	0.13
23	1.12	1.16	1.12	1.30	1.14	1.11	1.12	1.16	1.12	1.59	1.19	0.15
24	0.93	0.96	0.88	0.91	1.01	1.01	0.88	0.96	0.93	1.01	0.95	0.05
25	1.03	1.13	1.10	1.13	1.10	1.13	1.10	1.03	0.13	1.03	0.99	0.30
26	1.57	1.21	1.49	1.10	1.17	1.57	1.21	1.49	1.10	1.57	1.35	0.20
27	1.30	1.30	1.33	1.35	1.30	1.23	1.01	1.11	1.01	1.01	1.20	0.14
28	0.96	1.03	0.94	1.00	0.96	0.96	1.00	0.94	1.03	1.00	0.98	0.03
29	1.20	1.07	1.20	1.28	1.17	1.20	1.07	1.20	1.17	1.20	1.18	0.06
30	1.12	1.37	1.17	1.37	1.12	1.12	1.12	1.37	1.15	1.17	1.21	0.11
31	0.92	0.95	0.89	0.89	0.92	0.92	0.89	0.96	0.92	0.95	0.92	0.02
32	1.20	1.05	0.93	0.88	0.90	0.88	0.93	1.05	1.20	0.93	1.00	0.12
33	1.02	1.02	1.11	0.99	0.99	1.11	0.99	1.02	0.99	0.99	1.02	0.04
34	0.91	1.15	0.97	0.82	1.32	1.02	1.04	1.12	0.95	1.12	1.04	0.14
35	0.71	0.78	0.93	0.95	0.95	0.95	0.93	0.78	0.71	0.93	0.86	0.10
36	0.89	0.77	0.78	0.71	0.84	0.89	0.77	0.84	0.71	0.78	0.80	0.06
37	0.91	0.94	0.91	0.93	0.84	0.84	0.91	0.94	0.91	0.94	0.91	0.04
38	0.89	0.85	0.75	0.96	0.84	0.89	0.96	0.85	0.89	0.85	0.87	0.06
39	0.98	0.92	0.82	0.92	0.92	0.82	0.92	0.98	0.82	0.92	0.90	0.06
40	1.01	1.07	1.01	0.98	1.07	1.01	0.98	1.01	1.07	1.01	1.02	0.04
41	0.82	0.84	0.79	0.67	0.78	0.82	0.84	0.79	0.67	0.79	0.78	0.06
42	0.81	0.80	0.92	0.89	0.85	0.80	0.92	0.83	0.94	0.89	0.86	0.05
43	0.80	0.72	0.65	0.66	0.66	0.80	0.72	0.65	0.72	0.80	0.72	0.06
44	0.85	0.68	0.76	0.65	0.72	0.85	0.68	0.65	0.76	0.68	0.73	0.08
45	0.56	0.57	0.54	0.57	0.53	0.52	0.56	0.54	0.52	0.55	0.55	0.02
46	0.56	0.57	0.66	0.66	0.68	0.56	0.66	0.57	0.66	0.57	0.62	0.05
47	0.70	0.85	0.79	0.79	0.82	0.82	0.79	0.79	0.85	0.70	0.79	0.05
										Mean	*1.14*	*0.11*

Table C-6b the border experimental data of subject YT at condition 50 lux illumination.

No.	1	2	3	4	5	6	7	8	9	10	Average	Stnd Div
1	8.72	8.01	7.43	6.58	8.32	7.56	7.52	5.47	5.38	6.63	7.16	1.13
2	7.51	7.51	7.24	7.35	6.31	7.30	7.24	7.40	7.51	6.31	7.17	0.46
3	3.94	6.33	5.16	4.40	3.82	3.94	3.48	4.57	4.99	4.82	4.55	0.83
4	7.04	7.24	6.54	5.50	4.51	5.75	5.26	4.26	6.07	5.26	5.74	0.99
5	7.25	6.66	7.17	5.79	8.43	7.21	8.00	5.08	5.56	5.91	6.71	1.10
6	6.30	6.41	6.51	6.41	6.13	5.97	6.41	6.51	6.33	5.24	6.22	0.39
7	5.59	6.59	5.41	6.63	6.02	5.92	5.76	5.45	5.39	6.02	5.88	0.45
8	4.86	5.90	4.84	4.28	3.72	3.80	5.40	3.19	3.40	3.93	4.33	0.89
9	7.73	7.09	6.59	5.54	6.41	6.32	5.81	6.59	6.41	7.09	6.56	0.64
10	6.24	5.99	5.21	5.21	4.59	5.37	4.48	6.13	4.45	5.21	5.29	0.66
11	8.74	7.66	8.93	8.58	9.79	8.10	6.55	6.55	6.67	6.67	7.82	1.18
12	6.73	6.27	6.41	5.74	5.93	5.90	6.48	7.28	7.53	6.84	6.51	0.59
13	4.57	4.59	4.32	4.82	4.13	5.02	4.59	4.57	4.82	4.32	4.58	0.27
14	2.85	3.79	4.07	3.87	3.31	3.33	4.07	3.87	3.79	3.28	3.62	0.40
15	5.66	5.23	7.31	7.58	8.12	7.53	5.69	7.31	7.33	5.99	6.77	1.02
16	6.90	8.05	8.20	8.54	7.47	7.40	7.25	8.05	6.99	8.20	7.70	0.57
17	5.95	5.95	7.45	7.27	4.12	4.47	5.67	7.45	7.27	5.95	6.15	1.21
18	5.53	6.14	5.66	5.74	5.70	5.26	6.14	5.66	5.53	5.74	5.71	0.27
19	4.09	4.29	4.32	3.98	3.86	4.74	5.20	4.77	4.67	5.02	4.49	0.45
20	6.09	6.87	5.75	5.27	5.06	5.75	5.75	6.07	5.79	6.13	5.85	0.50
21	9.06	7.37	8.56	7.83	6.77	7.28	8.56	9.83	6.86	8.45	8.06	1.00
22	6.85	6.58	7.43	6.98	6.20	6.59	7.60	7.19	7.98	7.72	7.11	0.57
23	6.98	6.20	6.59	5.94	6.08	6.67	6.99	6.58	6.24	5.93	6.42	0.40
24	4.78	4.38	4.33	5.19	3.67	4.10	4.07	4.59	4.25	4.48	4.38	0.42
25	5.63	6.97	6.11	5.70	5.70	5.49	6.11	5.63	5.70	6.11	5.91	0.44
26	5.87	6.30	6.34	5.94	5.59	5.84	7.69	6.30	5.87	5.94	6.17	0.59
27	4.66	4.98	5.60	6.55	5.22	5.80	5.97	6.62	4.66	4.98	5.50	0.72
28	4.86	4.64	4.86	4.68	4.33	5.02	3.99	4.64	4.33	4.86	4.62	0.32
29	5.61	5.60	5.50	5.79	6.86	7.37	6.59	5.05	5.07	4.46	5.79	0.90
30	5.37	6.04	5.73	5.37	5.24	5.72	5.12	6.00	5.33	5.37	5.53	0.32
31	5.43	5.40	5.82	5.93	4.84	4.25	4.56	4.37	5.96	5.82	5.24	0.67
32	4.86	4.81	5.49	3.72	3.81	4.67	5.28	4.54	3.97	4.86	4.60	0.60
33	3.83	4.78	4.84	4.80	3.83	3.97	4.75	4.85	4.58	4.21	4.44	0.44
34	5.01	6.25	6.09	5.53	5.06	5.36	6.72	5.90	5.51	4.95	5.64	0.59
35	5.99	4.80	5.75	4.58	5.42	4.75	4.80	5.75	5.99	4.99	5.28	0.56
36	5.68	4.50	4.45	3.17	4.11	4.32	4.56	4.50	5.68	4.50	4.55	0.72
37	4.15	5.34	4.95	4.04	4.52	5.34	5.00	4.95	4.04	4.52	4.68	0.50
38	4.13	5.00	4.95	4.13	4.27	4.40	5.00	4.12	4.95	4.27	4.52	0.40
39	7.15	6.35	5.43	3.17	3.22	4.09	6.35	7.13	6.33	5.22	5.44	1.50
40	3.36	3.58	3.29	4.71	4.24	4.12	4.06	4.73	4.71	3.37	4.02	0.59
41	4.10	3.71	5.22	3.29	2.68	3.43	4.33	4.39	4.21	3.43	3.88	0.72
42	4.83	4.68	5.01	4.59	4.77	4.79	3.84	3.84	4.52	4.24	4.51	0.41
43	2.29	2.26	2.66	3.48	2.29	2.66	3.48	2.29	2.26	2.66	2.63	0.48
44	2.98	2.51	2.25	2.91	3.53	3.86	3.07	3.07	3.07	2.37	2.96	0.50
45	2.86	2.48	2.01	2.37	2.14	2.54	2.01	2.33	2.00	2.49	2.32	0.28
46	3.62	3.83	4.17	2.30	2.25	2.11	1.92	2.41	1.90	2.24	2.67	0.85
47	2.29	1.60	2.01	2.75	2.03	1.96	1.86	2.03	1.69	2.32	2.05	0.33
										Mean	*5.27*	*0.63*

APPENDIX D

The Data of The Brightness Matching Experiment

Table D-1a the brightness matching experimental data of subject KJ at condition 5 lux illumination.

No.	1	2	3	4	5	6	7	8	9	10	Average	Stnd Div
1	1.65	0.93	1.02	1.52	1.00	1.63	1.33	1.45	1.12	1.25	1.29	0.27
2	1.51	1.36	1.90	1.65	1.32	1.64	1.45	1.32	1.85	1.11	1.51	0.25
3	2.06	1.38	1.68	2.06	1.33	1.77	1.33	1.33	1.63	1.33	1.59	0.30
4	3.12	1.09	2.13	2.33	1.66	1.97	2.36	3.00	2.99	2.33	2.30	0.64
5	2.05	1.85	1.30	2.33	1.96	2.33	1.54	2.05	1.66	2.11	1.92	0.33
6	1.41	1.68	1.23	1.56	1.33	1.68	1.85	1.66	1.41	1.23	1.50	0.21
7	1.06	0.79	0.71	1.00	0.99	1.11	1.32	0.86	0.99	1.00	0.98	0.17
8	0.59	0.51	0.74	0.66	0.69	0.79	0.51	0.87	0.55	0.87	0.68	0.14
9	1.64	2.33	1.78	1.87	2.00	1.63	1.76	1.99	2.87	1.33	1.92	0.43
10	3.18	1.51	1.88	3.02	2.97	2.45	1.85	1.96	2.33	2.46	2.36	0.56
11	1.84	1.46	2.10	1.96	2.03	1.76	1.66	1.45	1.37	1.85	1.75	0.26
12	2.20	1.28	0.87	0.97	1.12	1.33	1.33	1.66	0.99	1.33	1.31	0.39
13	1.07	1.21	1.03	1.23	1.07	1.54	1.30	0.99	1.21	1.03	1.17	0.17
14	1.26	0.64	0.91	1.33	1.00	0.77	1.24	1.26	0.91	0.88	1.02	0.24
15	2.67	1.12	2.80	2.66	1.87	2.45	2.32	2.15	2.33	2.16	2.25	0.49
16	1.79	1.45	2.02	1.66	1.33	1.49	2.00	2.15	1.97	1.66	1.75	0.28
17	0.79	1.35	1.14	1.35	1.26	1.33	1.54	0.86	0.77	1.33	1.17	0.27
18	1.43	0.65	1.12	0.79	1.23	1.33	1.23	0.97	1.33	1.00	1.11	0.25
19	0.79	0.92	0.84	0.89	1.00	0.66	0.97	1.23	0.97	0.97	0.92	0.15
20	3.03	2.07	2.04	2.33	3.22	2.69	2.46	2.63	2.10	2.37	2.49	0.40
21	1.92	2.24	1.19	2.25	2.36	1.65	1.97	2.37	2.12	2.00	2.01	0.36
22	1.87	1.05	1.96	2.02	1.66	1.90	2.00	1.33	1.87	1.52	1.72	0.32
23	1.12	0.87	1.24	1.04	0.97	1.21	1.03	0.99	1.00	0.99	1.05	0.11
24	0.57	0.51	1.16	0.58	0.75	0.52	0.76	0.65	0.75	0.57	0.68	0.19
25	0.86	1.51	0.96	1.65	1.23	1.55	1.63	1.33	1.76	1.10	1.36	0.31
26	1.03	1.82	1.85	2.53	1.97	2.03	1.66	1.85	1.57	2.33	1.86	0.41
27	0.75	0.84	1.14	0.98	1.33	0.99	1.11	1.33	0.99	0.89	1.03	0.19
28	0.84	0.68	0.98	0.55	0.67	0.87	0.66	0.99	1.00	1.13	0.83	0.19
29	1.74	1.71	2.03	1.97	2.33	1.59	1.87	2.02	1.87	1.75	1.89	0.21
30	1.05	1.04	1.03	1.32	0.99	0.65	0.76	1.33	1.25	1.11	1.05	0.22
31	1.09	0.87	0.79	0.99	1.20	1.00	1.00	1.05	1.23	0.59	0.98	0.19
32	1.32	1.33	1.08	1.03	1.24	0.90	0.66	1.11	0.75	1.25	1.07	0.23
33	0.80	1.60	1.65	1.63	0.99	0.97	1.32	1.66	1.76	1.26	1.36	0.35
34	1.06	0.71	0.91	0.99	1.13	1.36	1.06	0.71	0.97	0.85	0.97	0.20
35	0.58	0.69	0.41	0.57	0.99	0.57	0.85	0.52	0.66	0.53	0.64	0.17
36	1.31	1.37	1.16	1.55	1.33	1.35	1.45	1.23	1.31	1.35	1.34	0.11
37	1.87	1.41	1.92	1.33	1.33	1.87	1.41	1.92	1.33	1.33	1.57	0.28
38	1.00	0.46	0.44	0.78	0.63	0.45	0.65	0.48	0.99	0.44	0.63	0.22
39	1.02	0.82	1.42	1.03	1.23	1.32	0.99	1.12	1.00	0.86	1.08	0.19
40	0.69	0.27	0.72	0.79	0.99	0.46	0.69	0.69	0.87	0.75	0.69	0.20
41	0.50	0.47	0.44	0.46	0.33	0.48	0.50	0.47	0.44	0.55	0.46	0.06
42	0.56	1.14	0.65	0.87	0.76	1.25	0.88	0.76	0.45	1.02	0.83	0.25
43	0.52	0.80	0.97	1.03	1.00	0.85	0.66	0.56	0.99	1.25	0.86	0.23
44	2.06	1.26	1.10	2.06	1.22	1.00	1.05	0.99	1.06	1.10	1.29	0.42
45	0.37	0.54	0.48	0.44	0.33	0.76	0.52	0.75	0.48	0.35	0.50	0.15
46	0.84	0.58	0.34	0.55	0.67	0.84	0.58	0.67	0.42	0.66	0.61	0.16
47	0.46	0.38	0.49	0.33	0.65	0.63	0.13	0.37	0.66	0.36	0.45	0.17
										Mean	*1.27*	*0.26*

Table D-1b the brightness matching experimental data of subject KJ at condition 50lux illumination.

No.	1	2	3	4	5	6	7	8	9	10	Average	Stnd Div
1	2.89	3.83	4.23	4.25	4.25	3.85	3.12	3.27	6.25	4.33	4.03	0.94
2	3.28	3.60	3.80	3.10	3.21	2.97	3.54	2.79	3.12	2.24	3.16	0.45
3	7.34	5.08	3.78	3.97	3.66	4.97	6.32	4.33	4.66	6.52	5.06	1.27
4	5.50	6.15	5.45	6.23	5.66	6.32	5.66	5.61	4.35	6.10	5.70	0.57
5	7.13	5.79	4.02	6.53	6.33	7.63	5.45	6.36	6.87	6.52	6.26	1.00
6	4.24	4.43	5.10	5.33	4.23	4.63	5.22	4.33	4.55	5.33	4.74	0.46
7	2.79	2.01	2.18	2.33	2.03	2.33	2.99	2.31	2.02	2.97	2.40	0.38
8	2.88	2.76	2.15	2.12	2.35	2.00	2.55	1.99	2.15	2.12	2.31	0.32
9	7.37	7.14	6.41	7.22	6.55	7.02	6.90	6.42	6.25	7.11	6.84	0.40
10	7.04	4.22	6.62	3.49	5.67	6.99	6.55	4.66	5.67	6.34	5.72	1.23
11	2.45	3.50	3.46	2.51	3.22	3.12	2.02	3.33	3.66	3.45	3.07	0.55
12	2.61	2.27	4.03	2.35	2.10	2.37	3.20	2.02	2.32	2.13	2.54	0.62
13	3.11	1.98	1.92	2.22	2.12	1.33	2.85	1.23	1.86	2.02	2.06	0.58
14	2.35	1.47	1.80	1.57	1.37	1.85	2.02	2.17	1.99	1.75	1.83	0.31
15	5.07	3.74	2.35	4.33	4.96	3.99	4.23	2.66	3.45	4.67	3.94	0.92
16	5.57	4.77	3.36	5.62	4.85	4.52	3.87	4.62	5.21	4.65	4.70	0.70
17	4.37	3.94	2.54	4.12	3.56	3.75	3.00	3.67	4.25	3.33	3.65	0.57
18	2.06	3.93	2.48	1.94	3.23	2.66	3.42	2.66	3.85	3.42	2.96	0.71
19	2.38	2.32	1.21	1.80	1.33	1.55	1.85	2.22	2.35	2.45	1.95	0.46
20	4.02	3.07	2.42	3.55	4.02	3.86	3.22	3.78	3.45	3.00	3.44	0.52
21	2.79	4.90	4.07	4.52	4.33	2.65	3.27	4.34	4.25	4.00	3.91	0.75
22	2.84	2.11	1.64	2.76	2.00	1.76	1.66	2.46	2.33	1.22	2.08	0.52
23	2.95	2.44	1.81	2.75	2.97	3.22	1.52	2.00	2.33	2.12	2.41	0.56
24	1.90	2.18	2.18	1.12	1.85	1.75	1.66	2.02	1.54	1.15	1.74	0.38
25	4.15	3.57	5.08	4.57	4.87	3.97	5.33	4.33	5.08	4.23	4.52	0.56
26	3.03	3.27	4.27	4.33	3.52	3.88	4.22	3.25	3.25	3.63	3.67	0.48
27	2.51	2.61	1.21	1.93	2.20	1.86	2.65	1.56	2.33	1.66	2.05	0.49
28	2.38	3.03	1.71	1.63	1.66	2.02	2.66	2.33	2.12	1.96	2.15	0.46
29	1.76	1.58	1.58	1.62	1.86	1.80	1.87	1.22	1.65	1.23	1.62	0.23
30	1.59	3.80	2.99	2.33	2.34	2.90	3.66	1.54	1.99	2.02	2.52	0.80
31	2.91	3.24	2.66	3.22	2.12	2.46	3.00	2.75	2.65	2.33	2.73	0.37
32	1.41	1.54	0.90	1.00	1.11	1.33	1.45	1.00	1.33	1.86	1.29	0.30
33	2.12	2.14	1.08	2.33	2.12	2.00	1.22	1.85	1.63	2.00	1.85	0.41
34	1.19	1.66	1.02	1.33	2.00	2.00	1.66	1.64	2.37	1.66	1.65	0.41
35	2.44	1.86	1.51	2.33	1.33	1.33	1.52	2.32	1.55	1.00	1.72	0.50
36	0.85	1.55	1.09	1.33	1.62	1.44	1.15	1.25	1.25	0.55	1.21	0.32
37	1.28	1.35	1.25	1.33	1.55	1.10	0.99	1.33	1.63	1.10	1.29	0.20
38	1.17	1.41	1.17	1.33	1.54	1.23	1.33	1.33	1.25	1.33	1.31	0.11
39	1.75	2.17	1.74	1.87	2.22	2.10	1.66	1.80	1.85	1.85	1.90	0.19
40	1.24	0.99	1.25	1.23	0.90	1.01	0.90	1.33	1.23	0.99	1.11	0.16
41	1.95	2.56	2.27	1.99	2.42	2.33	2.27	2.42	2.33	1.87	2.24	0.23
42	1.18	0.92	0.64	0.75	0.99	1.11	0.87	0.92	0.76	0.64	0.88	0.19
43	1.06	1.22	1.16	1.11	1.06	1.24	0.99	1.16	1.21	1.00	1.12	0.09
44	1.60	2.53	1.13	1.22	1.16	2.22	1.65	1.87	1.53	1.24	1.62	0.47
45	1.41	1.06	1.17	1.30	1.00	1.17	1.33	1.32	0.65	1.42	1.18	0.23
46	2.99	0.70	0.90	0.79	2.97	1.33	1.02	0.85	1.14	1.33	1.40	0.86
47	0.92	0.47	0.56	0.76	0.70	0.86	0.97	0.42	0.63	0.80	0.71	0.19
										Mean	*2.73*	*0.50*

Table D-2a the brightness matching experimental data of subject NJ at condition 5 lux illumination**.**

No.	1	2	3	4	5	6	7	8	9	10	Average	Stnd Div
1	0.53	1.07	0.58	0.87	1.02	0.99	0.64	0.86	0.77	0.85	0.82	0.19
2	0.94	1.04	1.09	1.03	0.87	0.94	1.05	1.11	0.67	0.88	0.96	0.14
3	0.42	0.38	0.76	0.76	0.97	0.37	0.46	0.75	0.65	0.75	0.63	0.21
4	0.50	0.74	0.59	0.79	0.66	0.75	0.64	0.72	0.50	0.75	0.66	0.11
5	1.73	0.89	0.68	0.88	0.98	1.46	1.23	0.96	0.77	1.11	1.07	0.32
6	0.91	0.48	0.45	0.99	1.02	0.99	1.33	0.86	0.99	1.36	0.94	0.30
7	1.00	0.77	1.12	1.22	1.02	0.85	1.00	0.77	1.12	1.02	0.99	0.15
8	0.45	0.41	0.46	0.66	0.75	0.42	0.54	0.65	0.75	0.65	0.58	0.13
9	0.96	1.01	1.11	0.99	0.79	0.96	1.01	1.26	0.87	0.96	0.99	0.13
10	1.46	1.51	0.94	1.63	1.86	1.67	1.53	1.63	1.58	1.25	1.51	0.25
11	1.30	1.85	1.37	0.97	1.25	1.43	1.69	1.66	1.25	1.58	1.43	0.26
12	0.64	0.55	0.63	0.66	0.63	0.65	0.85	0.67	0.85	0.67	0.68	0.10
13	0.25	0.18	0.34	0.53	0.54	0.66	0.55	0.46	0.63	0.55	0.47	0.16
14	0.48	0.55	0.41	0.23	0.19	0.42	0.33	0.22	0.33	0.33	0.35	0.12
15	1.28	0.96	1.60	1.65	1.33	1.66	1.00	1.24	1.33	0.99	1.30	0.27
16	1.14	1.45	0.71	1.57	1.33	1.23	1.14	1.33	1.45	0.87	1.22	0.27
17	0.71	0.76	0.56	0.77	0.57	0.87	0.77	0.85	0.67	0.56	0.71	0.12
18	0.44	0.55	0.69	0.62	0.44	0.33	0.55	0.69	0.32	0.46	0.51	0.13
19	0.27	0.37	0.37	0.22	0.31	0.13	0.19	0.26	0.33	0.42	0.29	0.09
20	0.56	0.35	0.48	0.63	0.75	0.65	0.46	0.67	0.46	0.66	0.57	0.13
21	1.10	0.73	0.55	1.23	1.12	1.33	1.33	1.13	1.23	1.33	1.11	0.26
22	0.56	0.56	0.38	0.91	0.59	0.46	0.75	0.46	0.55	0.56	0.58	0.15
23	0.47	0.33	0.47	0.46	0.25	0.33	0.33	0.16	0.46	0.46	0.37	0.11
24	0.43	0.33	0.84	0.32	0.21	0.24	0.13	0.32	0.21	0.22	0.33	0.20
25	0.55	0.48	0.45	0.59	0.60	0.99	0.87	0.75	0.45	0.66	0.64	0.18
26	0.78	0.61	0.50	0.77	0.46	0.33	0.45	0.23	0.25	0.26	0.46	0.20
27	0.43	0.70	0.60	0.76	0.70	0.63	0.88	0.76	0.45	0.75	0.67	0.14
28	0.37	0.36	0.36	0.32	0.13	0.12	0.23	0.15	0.42	0.33	0.28	0.11
29	0.53	0.85	0.69	0.53	0.99	0.86	0.90	0.75	0.57	0.65	0.73	0.16
30	0.53	0.59	0.73	0.54	0.58	0.68	0.75	0.76	0.66	0.55	0.64	0.09
31	0.34	0.45	0.45	0.47	0.55	0.65	0.42	0.24	0.16	0.46	0.42	0.14
32	0.29	0.21	0.21	0.21	0.13	0.33	0.15	0.22	0.22	0.21	0.22	0.06
33	0.39	0.48	0.54	0.53	0.63	0.52	0.53	0.53	0.43	0.77	0.54	0.10
34	0.48	0.54	0.52	0.45	0.42	0.33	0.25	0.24	0.24	0.47	0.39	0.12
35	0.41	0.52	0.41	0.52	0.53	0.46	0.53	0.47	0.46	0.33	0.46	0.07
36	0.52	0.52	0.59	0.37	0.57	0.75	0.75	0.87	0.45	0.24	0.56	0.19
37	0.55	0.59	0.50	0.57	0.54	0.53	0.56	0.54	0.23	0.50	0.51	0.10
38	0.57	0.36	0.87	0.88	0.56	0.58	0.45	0.43	0.23	0.46	0.54	0.21
39	0.34	0.46	0.65	0.34	0.45	0.25	0.33	0.48	0.33	0.33	0.40	0.12
40	0.44	0.52	0.50	0.57	0.52	0.44	0.47	0.33	0.27	0.27	0.43	0.11
41	0.31	0.39	0.49	0.29	0.24	0.33	0.42	0.16	0.23	0.42	0.33	0.10
42	0.52	0.53	0.53	0.53	0.54	0.43	0.33	0.63	0.45	0.63	0.51	0.09
43	0.52	0.33	0.22	0.24	0.33	0.42	0.33	0.53	0.33	0.42	0.37	0.11
44	0.27	0.37	0.23	0.26	0.26	0.33	0.24	0.27	0.33	0.26	0.28	0.04
45	0.38	0.53	0.43	0.52	0.33	0.24	0.23	0.26	0.63	0.33	0.39	0.14
46	0.30	0.34	0.27	0.21	0.33	0.69	0.42	0.52	0.21	0.21	0.35	0.16
47	0.22	0.22	0.21	0.21	0.17	0.20	0.23	0.42	0.22	0.20	0.23	0.07
										Mean	*0.63*	*0.15*

Table D-2b the brightness matching experimental data of subject NJ at condition 50lux illumination.

No.	1	2	3	4	5	6	7	8	9	10	Average	Stnd Div
1	9.43	6.63	4.94	6.63	9.43	7.27	5.24	6.33	9.27	5.33	7.05	1.76
2	6.62	6.20	9.80	6.66	6.12	7.10	6.00	6.24	7.33	9.27	7.13	1.34
3	3.36	3.73	4.49	3.62	4.11	3.33	4.41	3.13	4.22	4.24	3.86	0.49
4	6.64	7.98	7.34	6.63	7.11	6.25	7.33	6.14	7.27	7.11	6.98	0.56
5	7.21	6.46	5.95	6.23	6.00	6.55	7.00	6.25	6.33	7.25	6.52	0.48
6	5.36	5.39	4.75	3.17	4.33	5.24	6.22	5.00	5.24	6.33	5.10	0.91
7	3.86	3.07	3.62	3.55	3.64	4.02	2.96	3.34	3.25	3.08	3.44	0.36
8	4.76	2.35	3.09	4.10	3.65	3.23	4.02	3.25	4.02	4.58	3.71	0.74
9	2.24	4.48	5.24	4.25	5.23	4.25	2.97	4.00	4.02	4.48	4.12	0.92
10	5.89	5.99	7.82	5.24	6.22	6.33	7.12	5.99	5.63	6.33	6.25	0.74
11	3.65	4.07	2.80	4.02	3.62	3.51	4.20	4.11	3.53	4.00	3.75	0.42
12	2.47	2.27	2.70	2.27	2.45	2.87	3.00	2.70	2.54	2.37	2.56	0.25
13	3.61	2.72	4.20	3.87	4.52	2.42	3.65	3.79	3.89	3.89	3.66	0.63
14	4.21	2.92	2.98	2.99	2.82	4.45	2.34	2.85	2.92	2.99	3.15	0.65
15	3.04	2.99	2.94	3.22	2.75	2.86	3.13	3.11	3.51	2.41	3.00	0.29
16	5.00	4.92	5.68	4.57	4.71	5.00	4.43	4.75	4.85	4.89	4.88	0.34
17	2.80	3.10	3.13	3.13	2.86	3.11	3.52	2.03	3.22	2.86	2.97	0.39
18	2.61	2.82	3.18	2.89	3.52	3.23	2.89	2.97	3.13	3.25	3.05	0.26
19	1.63	2.30	1.69	1.75	1.85	1.63	2.13	2.33	2.00	1.99	1.93	0.26
20	4.32	3.41	4.88	3.45	4.85	4.33	3.85	4.11	3.96	4.56	4.17	0.52
21	6.96	6.96	5.67	5.66	6.33	5.63	6.25	5.52	6.90	5.70	6.16	0.60
22	4.06	4.68	4.98	4.94	4.03	4.63	4.63	4.96	4.63	5.00	4.65	0.36
23	4.21	3.91	4.39	3.27	4.33	2.96	3.15	4.63	4.22	2.12	3.72	0.81
24	3.31	2.53	3.37	3.65	2.22	3.13	2.87	3.13	2.36	3.52	3.01	0.50
25	6.69	7.69	5.63	6.35	7.02	6.85	6.53	7.24	6.33	5.36	6.57	0.70
26	3.52	3.42	4.06	3.65	3.41	4.01	3.27	4.22	3.85	4.15	3.76	0.34
27	3.67	4.08	4.61	4.22	3.63	4.52	4.00	3.96	4.25	4.03	4.10	0.32
28	2.56	2.01	3.15	2.05	2.66	2.64	2.47	2.87	3.41	3.13	2.69	0.46
29	2.70	3.26	3.12	2.85	3.54	2.13	2.37	2.58	3.27	2.59	2.84	0.45
30	5.01	3.19	4.14	4.12	3.52	5.00	4.70	3.96	4.15	3.66	4.14	0.61
31	2.80	2.91	3.05	2.85	3.13	2.66	2.99	2.37	3.22	2.99	2.89	0.25
32	2.59	2.90	3.85	2.57	2.87	2.97	3.13	3.25	2.99	2.79	2.99	0.37
33	2.51	4.56	3.85	4.86	3.23	3.66	3.55	4.12	2.99	3.16	3.65	0.72
34	2.59	2.05	1.17	2.01	2.05	1.23	2.00	2.43	1.86	2.34	1.97	0.47
35	3.65	3.09	1.97	2.22	1.58	2.11	3.05	2.42	3.02	1.99	2.51	0.66
36	3.77	1.87	3.08	2.89	3.15	2.64	3.54	1.86	3.52	2.86	2.92	0.66
37	2.53	2.14	3.10	2.77	2.52	3.03	2.85	3.12	2.85	2.43	2.73	0.32
38	2.44	2.30	2.65	2.54	2.22	2.69	2.47	2.00	2.20	2.21	2.37	0.22
39	2.11	3.10	3.10	2.99	2.55	2.76	2.63	2.13	2.90	2.00	2.62	0.42
40	3.66	4.65	3.78	4.33	3.23	4.12	3.87	4.22	3.84	3.22	3.89	0.46
41	3.28	2.78	2.89	2.55	2.89	3.48	2.86	2.96	3.00	2.55	2.92	0.29
42	2.38	2.57	2.57	4.02	2.42	2.00	3.23	1.03	2.37	2.35	2.49	0.77
43	2.69	2.56	3.90	2.36	3.12	2.13	2.99	3.22	2.35	2.89	2.82	0.52
44	2.63	1.26	1.90	2.34	2.45	2.33	1.90	2.22	3.25	2.13	2.24	0.52
45	2.13	4.53	2.49	4.24	2.58	2.37	3.25	2.65	3.22	2.51	3.00	0.81
46	2.20	2.46	1.56	2.52	2.32	1.99	2.33	2.22	2.32	1.97	2.19	0.28
47	2.34	2.30	3.17	2.33	2.23	2.37	3.10	2.33	2.48	2.40	2.50	0.34
										Mean	*3.74*	*0.54*

Table D-3a the brightness matching experimental data of subject PP at condition 5 lux illumination.

No.	1	2	3	4	5	6	7	8	9	10	Average	Stnd Div
1	1.94	2.31	2.89	1.93	2.12	1.78	2.01	1.99	2.16	2.38	2.15	0.32
2	4.33	3.23	3.91	3.62	3.16	3.63	4.32	3.13	3.01	3.51	3.58	0.48
3	2.60	1.74	2.87	2.66	2.16	1.73	1.83	2.13	1.83	2.16	2.17	0.41
4	3.67	2.80	3.74	3.67	3.17	3.11	3.61	3.17	2.98	3.13	3.30	0.34
5	4.06	4.00	3.57	4.12	3.63	3.67	3.68	3.49	4.01	3.83	3.81	0.23
6	2.74	2.76	2.76	2.66	2.93	2.81	2.82	2.61	2.99	2.61	2.77	0.13
7	2.36	2.03	1.93	2.16	2.11	1.99	2.17	2.11	1.98	2.11	2.10	0.12
8	1.88	1.64	2.05	2.33	1.61	1.49	1.61	1.18	2.11	1.63	1.75	0.34
9	2.52	2.63	3.46	3.71	3.61	3.17	3.61	3.11	2.95	3.17	3.19	0.41
10	4.09	4.90	2.61	4.17	4.63	4.18	3.83	4.21	3.33	3.71	3.97	0.65
11	3.86	3.29	2.75	3.17	2.99	3.51	3.26	2.99	3.27	3.83	3.29	0.36
12	1.59	2.35	2.47	2.33	2.51	1.93	1.82	1.92	2.33	2.16	2.14	0.31
13	1.61	2.27	2.04	2.12	1.79	2.16	2.33	1.83	2.51	2.32	2.10	0.28
14	1.50	1.64	1.82	1.49	1.78	1.93	1.27	1.33	1.17	1.81	1.57	0.26
15	3.66	4.27	3.58	3.66	4.33	3.66	4.32	3.13	3.83	4.11	3.85	0.39
16	2.38	6.06	5.63	5.03	4.33	4.61	5.61	5.16	4.67	4.32	4.78	1.03
17	2.81	5.06	3.81	4.16	3.82	3.61	5.11	4.11	3.16	4.66	4.03	0.76
18	1.46	1.87	1.75	1.80	1.78	1.99	2.03	2.06	1.99	1.51	1.82	0.21
19	1.98	2.22	2.20	1.51	1.51	1.48	1.33	1.38	1.93	1.32	1.69	0.36
20	2.72	2.64	3.39	2.66	3.12	2.66	3.33	2.61	2.66	3.16	2.90	0.32
21	4.10	4.67	3.98	4.33	4.66	4.12	3.76	3.76	4.32	4.77	4.25	0.37
22	2.44	2.65	3.32	2.92	3.84	2.33	2.67	2.48	2.44	2.62	2.77	0.47
23	2.14	1.79	2.23	2.56	2.16	1.83	1.98	2.51	2.49	2.33	2.20	0.28
24	1.20	1.36	1.38	1.38	1.61	1.63	1.76	1.28	1.18	1.34	1.41	0.19
25	3.55	3.24	3.42	3.67	3.16	3.63	3.43	3.55	3.24	3.63	3.45	0.18
26	4.00	3.22	3.38	3.63	3.33	3.82	3.93	3.45	3.62	3.44	3.58	0.26
27	2.51	2.64	3.25	2.66	2.64	3.00	2.66	2.16	2.62	2.66	2.68	0.28
28	1.59	1.55	1.54	1.59	1.53	1.43	1.63	1.32	1.63	1.48	1.53	0.10
29	1.79	3.31	3.72	2.40	3.16	3.67	3.11	2.43	3.13	2.16	2.89	0.65
30	2.39	2.08	2.27	2.12	2.82	1.61	2.63	1.63	2.82	2.33	2.27	0.43
31	2.43	3.08	3.02	3.21	2.61	2.06	2.32	2.66	2.66	2.93	2.70	0.36
32	2.20	2.24	1.61	1.78	1.83	1.93	2.26	2.12	1.76	1.89	1.96	0.23
33	2.00	1.78	1.65	2.16	1.95	2.31	2.01	1.83	1.77	1.95	1.94	0.20
34	2.74	2.66	1.86	3.18	2.81	3.13	2.82	3.16	2.66	2.83	2.78	0.38
35	1.99	1.85	2.41	2.28	2.31	1.93	1.88	2.31	1.73	1.76	2.04	0.26
36	1.66	1.58	2.14	2.06	1.93	1.77	1.63	1.61	1.93	2.26	1.86	0.24
37	3.47	2.08	2.50	3.26	2.61	2.82	2.82	3.11	2.39	2.66	2.77	0.42
38	2.00	1.62	1.46	2.11	2.11	1.66	1.73	2.16	1.61	2.16	1.86	0.27
39	1.27	2.19	1.81	1.16	1.06	1.18	1.33	1.16	1.63	1.77	1.46	0.37
40	1.59	1.69	1.82	1.99	2.28	1.82	1.43	1.71	1.61	1.89	1.78	0.24
41	2.94	1.98	1.90	1.45	2.61	2.61	1.63	1.11	1.61	1.23	1.91	0.63
42	1.81	1.74	1.92	1.78	2.01	1.48	1.56	1.61	1.48	1.19	1.66	0.24
43	1.47	1.35	1.65	1.28	1.53	1.43	1.56	1.61	1.61	1.27	1.48	0.14
44	1.59	1.24	1.39	1.98	1.33	1.11	1.16	1.76	1.71	1.06	1.43	0.31
45	1.54	1.10	1.22	1.50	1.06	1.23	1.38	1.07	1.02	1.28	1.24	0.19
46	1.34	1.06	1.39	1.33	1.60	1.00	1.07	1.32	1.06	1.18	1.24	0.19
47	0.84	0.66	1.15	1.08	1.33	0.81	0.66	0.77	0.76	0.76	0.88	0.23
										Mean	*2.45*	*0.34*

Table D-3b the brightness matching experimental data of subject PP at condition 50lux illumination.

No.	1	2	3	4	5	6	7	8	9	10	Average	Stnd Div
1	3.92	6.32	4.13	3.96	4.22	5.12	4.33	3.97	4.02	3.88	4.39	0.77
2	5.21	5.47	6.31	5.12	6.00	5.63	5.21	5.04	5.12	4.93	5.40	0.45
3	5.20	6.21	5.24	5.30	6.02	6.32	5.63	5.42	5.63	6.33	5.73	0.45
4	6.49	6.64	7.23	6.46	6.33	6.49	6.46	7.05	6.76	6.55	6.65	0.29
5	8.75	8.87	8.04	8.25	8.36	7.99	9.12	8.77	8.45	8.33	8.49	0.37
6	7.29	7.26	9.18	7.55	7.66	8.37	8.00	7.46	6.99	7.63	7.74	0.64
7	2.99	4.31	4.37	4.57	3.88	5.64	4.32	3.75	4.26	4.76	4.28	0.69
8	3.45	4.43	4.99	4.12	4.86	3.79	5.12	4.76	4.32	4.24	4.41	0.54
9	8.56	5.81	8.56	7.33	8.24	7.96	8.64	7.24	6.88	7.33	7.65	0.91
10	6.46	4.27	7.56	6.45	6.25	4.33	5.33	6.22	7.33	8.03	6.22	1.27
11	10.0	10.4	7.47	10.2	8.23	9.25	10.0	10.2	9.25	10.2	9.55	1.00
12	4.58	3.82	2.95	3.66	4.00	4.26	3.79	2.95	4.26	4.76	3.90	0.61
13	5.69	7.31	4.31	5.75	6.55	7.59	4.75	5.33	7.25	6.22	6.08	1.11
14	2.61	1.47	3.10	3.66	2.79	2.56	3.25	3.66	2.79	3.10	2.90	0.64
15	5.87	4.16	6.03	5.90	4.32	5.27	6.25	4.22	5.02	4.02	5.11	0.88
16	6.33	6.90	6.29	6.66	6.02	6.32	5.90	6.55	5.25	7.12	6.33	0.53
17	5.82	9.18	8.47	7.86	9.27	8.63	7.33	8.26	9.27	6.76	8.08	1.15
18	6.33	5.38	5.45	6.32	6.75	5.32	5.86	6.42	5.55	6.25	5.96	0.51
19	4.96	4.64	3.86	4.72	4.21	3.96	4.33	4.76	3.76	4.22	4.34	0.41
20	5.19	5.79	5.66	5.24	5.21	4.99	5.12	4.78	5.33	5.21	5.25	0.30
21	9.93	6.50	6.77	7.24	8.47	7.21	6.33	7.21	6.48	6.21	7.23	1.15
22	9.94	10.1	10.7	10.3	9.55	10.2	9.65	8.32	10.6	8.80	9.83	0.78
23	4.60	5.35	5.13	4.86	5.40	5.15	4.21	5.63	4.23	5.33	4.99	0.49
24	3.57	6.06	4.33	5.33	4.37	5.27	4.25	6.85	6.01	4.21	5.03	1.05
25	5.53	5.11	5.70	6.21	5.33	5.45	6.33	5.12	5.23	5.80	5.58	0.43
26	6.62	6.83	10.2	9.23	7.02	6.79	6.80	6.83	6.23	6.62	7.32	1.30
27	5.10	4.59	5.05	4.88	5.41	4.27	5.33	5.13	4.86	5.27	4.99	0.35
28	4.56	5.84	5.78	4.77	5.33	4.25	5.36	4.76	5.33	4.29	5.03	0.58
29	3.92	2.91	2.94	3.87	3.22	3.75	2.43	3.45	3.88	3.92	3.43	0.53
30	4.53	5.68	2.91	4.31	5.33	4.33	4.29	4.27	4.88	5.74	4.63	0.84
31	4.70	7.02	5.84	4.67	6.33	4.24	4.87	7.01	5.84	5.33	5.58	0.99
32	7.28	8.41	9.78	9.78	7.37	8.56	9.22	8.15	9.22	7.63	8.54	0.94
33	4.17	3.13	2.98	4.24	3.15	3.42	3.00	3.69	4.10	3.46	3.53	0.49
34	4.26	3.46	3.48	4.63	3.05	4.32	3.11	3.25	4.22	3.48	3.73	0.57
35	6.37	8.04	6.59	8.02	7.86	6.52	6.79	7.57	8.22	6.32	7.23	0.78
36	4.70	4.29	4.70	5.13	4.56	5.24	4.19	4.79	5.05	4.56	4.72	0.34
37	3.63	3.33	2.76	3.05	3.15	2.88	3.37	3.55	3.22	2.55	3.15	0.34
38	4.52	4.59	4.68	5.16	4.36	4.87	5.30	4.79	4.63	5.27	4.82	0.33
39	3.36	3.77	4.07	3.75	4.23	3.55	4.13	3.88	3.47	3.75	3.80	0.29
40	5.25	6.51	4.56	5.33	6.25	5.15	6.25	5.37	4.66	5.21	5.45	0.67
41	3.72	4.71	4.09	2.36	3.58	4.85	3.22	3.96	4.02	3.79	3.83	0.71
42	4.26	2.83	2.52	4.33	2.99	2.77	3.46	4.27	4.33	3.25	3.50	0.73
43	5.30	6.31	8.63	6.46	5.33	6.15	7.22	6.25	5.33	6.22	6.32	1.01
44	2.09	1.78	1.64	2.01	1.99	1.76	1.76	2.04	1.99	1.88	1.89	0.15
45	2.83	2.93	3.12	2.87	3.25	2.75	3.15	3.45	2.99	2.75	3.01	0.23
46	2.38	2.32	2.00	1.99	2.59	2.63	2.10	1.96	2.45	2.31	2.27	0.25
47	3.58	2.71	2.88	3.52	2.79	2.96	3.15	3.02	3.55	2.79	3.10	0.34
										Mean	*5.34*	*0.64*

Table D-4a the brightness matching experimental data of subject PS at condition 5 lux illumination.

No.	1	2	3	4	5	6	7	8	9	10	Average	Stnd Div
1	0.44	0.71	0.76	0.67	0.78	0.88	0.98	1.22	1.00	1.12	0.86	0.23
2	0.99	0.86	0.75	0.77	0.99	0.75	0.66	0.75	0.66	0.77	0.79	0.12
3	0.42	0.46	0.42	0.60	0.50	0.42	0.45	0.55	0.55	0.46	0.48	0.06
4	0.89	0.89	0.84	0.79	0.86	0.87	0.98	0.76	0.90	0.76	0.85	0.07
5	0.77	0.55	0.75	0.86	0.86	0.75	1.00	0.75	0.69	0.88	0.78	0.12
6	0.51	0.56	0.40	0.55	0.43	0.56	0.51	0.40	0.55	0.43	0.49	0.07
7	0.43	0.45	0.46	0.35	0.53	0.50	0.45	0.33	0.56	0.43	0.45	0.07
8	0.28	0.30	0.30	0.22	0.30	0.22	0.28	0.22	0.30	0.30	0.27	0.04
9	0.69	0.51	0.66	0.75	0.50	0.55	0.66	0.74	0.66	0.66	0.64	0.09
10	1.04	1.33	0.94	0.86	1.06	0.99	1.04	1.33	0.94	1.06	1.06	0.16
11	0.87	0.94	0.89	0.94	0.77	0.88	0.88	0.87	0.76	0.77	0.86	0.07
12	0.62	0.82	0.59	0.67	0.82	0.64	0.87	0.98	0.76	0.82	0.76	0.13
13	0.21	0.37	0.28	0.23	0.28	0.45	0.43	0.37	0.28	0.21	0.32	0.09
14	0.28	0.29	0.18	0.21	0.37	0.15	0.33	0.22	0.19	0.17	0.24	0.07
15	0.91	0.80	0.85	0.99	1.33	0.97	0.79	0.87	0.97	1.00	0.95	0.15
16	0.61	0.50	0.69	0.77	0.65	0.69	0.58	0.69	0.75	0.65	0.66	0.08
17	0.38	0.51	0.53	0.57	0.75	0.66	0.75	0.63	0.75	0.51	0.60	0.13
18	0.42	0.44	0.34	0.45	0.66	0.38	0.53	0.44	0.46	0.33	0.44	0.10
19	0.24	0.44	0.37	0.25	0.23	0.24	0.36	0.26	0.43	0.43	0.33	0.09
20	0.30	0.48	0.43	0.46	0.35	0.27	0.37	0.45	0.33	0.32	0.38	0.07
21	0.92	0.64	0.69	0.55	0.69	0.69	0.96	0.86	0.88	0.66	0.75	0.14
22	0.70	0.88	0.58	0.77	0.90	0.77	0.66	0.88	0.89	0.66	0.77	0.11
23	0.37	0.31	0.37	0.31	0.33	0.45	0.48	0.37	0.46	0.38	0.38	0.06
24	0.28	0.33	0.25	0.24	0.26	0.36	0.25	0.28	0.23	0.27	0.27	0.04
25	0.65	0.62	0.48	0.45	0.55	0.43	0.43	0.66	0.64	0.43	0.53	0.10
26	0.50	0.63	0.61	0.63	0.62	0.55	0.42	0.52	0.43	0.56	0.55	0.08
27	0.36	0.46	0.53	0.33	0.57	0.42	0.36	0.32	0.45	0.32	0.41	0.09
28	0.39	0.30	0.32	0.39	0.47	0.29	0.27	0.21	0.32	0.20	0.31	0.08
29	0.35	0.27	0.29	0.35	0.33	0.30	0.37	0.28	0.33	0.23	0.31	0.04
30	0.42	0.45	0.59	0.57	0.62	0.61	0.59	0.53	0.63	0.42	0.54	0.08
31	0.39	0.39	0.34	0.31	0.43	0.30	0.35	0.39	0.34	0.30	0.35	0.05
32	0.51	0.51	0.52	0.52	0.42	0.33	0.43	0.33	0.51	0.52	0.46	0.08
33	0.52	0.54	0.63	0.63	0.53	0.60	0.50	0.30	0.52	0.52	0.53	0.09
34	0.48	0.39	0.43	0.35	0.42	0.33	0.42	0.37	0.48	0.39	0.40	0.05
35	0.37	0.35	0.28	0.32	0.37	0.34	0.25	0.33	0.34	0.36	0.33	0.04
36	0.43	0.37	0.34	0.43	0.32	0.31	0.36	0.35	0.45	0.33	0.37	0.05
37	0.34	0.32	0.32	0.35	0.34	0.29	0.42	0.33	0.35	0.32	0.34	0.03
38	0.34	0.55	0.32	0.31	0.30	0.31	0.34	0.32	0.31	0.32	0.34	0.07
39	0.43	0.34	0.56	0.43	0.52	0.32	0.33	0.46	0.30	0.34	0.40	0.09
40	0.29	0.41	0.23	0.30	0.36	0.13	0.23	0.40	0.41	0.30	0.30	0.09
41	0.21	0.12	0.21	0.14	0.33	0.13	0.20	0.23	0.21	0.12	0.19	0.07
42	0.37	0.33	0.31	0.33	0.37	0.39	0.42	0.31	0.33	0.37	0.35	0.04
43	0.33	0.27	0.29	0.33	0.37	0.33	0.23	0.20	0.33	0.37	0.30	0.06
44	0.34	0.38	0.35	0.36	0.34	0.35	0.35	0.33	0.37	0.34	0.35	0.02
45	0.29	0.26	0.31	0.24	0.22	0.29	0.26	0.31	0.23	0.33	0.27	0.04
46	0.41	0.34	0.54	0.57	0.51	0.50	0.36	0.54	0.23	0.34	0.43	0.11
47	0.30	0.21	0.25	0.22	0.20	0.31	0.33	0.21	0.21	0.19	0.24	0.05
										Mean	*0.49*	*0.08*

Table D-4b the brightness matching experimental data of subject PS at condition 50lux illumination.

No.	1	2	3	4	5	6	7	8	9	10	Average	Stnd Div
1	7.88	7.34	6.41	7.22	6.33	7.85	6.97	7.22	6.55	7.22	7.0968	0.54
2	5.84	6.51	8.23	5.23	6.52	5.63	7.22	5.33	6.86	8.22	6.5589	1.09
3	6.80	6.80	6.33	5.22	6.33	7.22	6.99	6.67	6.33	5.33	6.3998	0.66
4	5.06	5.16	3.87	5.33	5.69	5.32	5.63	4.97	5.00	6.33	5.2357	0.63
5	5.16	4.53	6.23	5.33	6.22	4.22	5.23	6.25	4.33	6.23	5.3729	0.83
6	2.91	2.78	3.60	3.23	2.23	3.10	2.99	2.66	3.22	3.58	3.0293	0.42
7	3.46	3.29	3.40	2.33	3.26	2.33	3.25	3.65	3.12	3.00	3.1094	0.45
8	3.75	2.66	2.71	2.33	2.00	2.33	2.65	3.13	2.53	2.13	2.6214	0.51
9	4.39	4.53	5.21	4.63	4.32	2.88	3.22	4.21	4.33	4.33	4.2042	0.67
10	4.79	3.75	3.75	4.79	4.86	4.22	4.63	4.21	5.02	3.86	4.3897	0.49
11	3.15	3.65	4.51	4.66	4.79	3.26	3.75	3.66	4.63	4.63	4.0685	0.63
12	3.36	3.09	2.91	3.09	3.00	2.99	3.42	3.33	2.96	3.25	3.1395	0.19
13	3.10	3.15	3.05	2.97	3.00	2.88	2.76	3.13	3.02	3.06	3.0101	0.12
14	1.23	1.37	1.27	1.33	1.52	1.43	2.02	1.75	1.85	1.12	1.4895	0.29
15	3.04	3.63	3.45	4.02	3.63	4.33	3.52	3.02	3.85	3.27	3.5768	0.42
16	2.78	3.93	3.70	2.86	3.66	2.96	3.25	2.76	3.22	3.25	3.2367	0.41
17	3.81	4.60	4.45	3.85	3.25	3.21	3.63	4.02	3.99	3.27	3.8080	0.48
18	2.94	2.75	2.63	2.12	2.03	2.52	2.66	2.65	2.15	2.35	2.4811	0.30
19	1.75	1.74	1.42	1.12	1.86	1.66	1.99	1.65	1.65	1.22	1.6066	0.27
20	3.33	3.98	4.97	4.53	4.66	3.85	3.76	3.66	3.55	3.21	3.9483	0.59
21	3.07	4.16	3.29	3.12	3.25	3.15	3.12	3.12	3.43	4.02	3.3745	0.39
22	3.74	4.36	4.12	3.53	4.13	3.27	4.33	3.66	3.86	3.79	3.8765	0.35
23	3.76	3.56	3.50	3.45	3.52	3.87	4.33	3.22	3.00	3.15	3.5361	0.38
24	2.21	2.30	1.67	2.21	2.33	2.33	2.54	2.10	3.22	1.25	2.2161	0.51
25	4.56	4.63	4.05	4.69	3.96	4.79	4.12	3.25	4.97	4.00	4.3024	0.52
26	3.49	3.24	3.24	4.02	4.13	3.66	4.63	3.65	3.55	3.65	3.7253	0.43
27	2.90	2.51	2.39	2.55	2.75	2.65	2.46	2.35	2.99	2.46	2.6010	0.22
28	3.04	2.51	2.03	2.01	1.96	1.88	2.33	3.02	1.88	2.36	2.3010	0.44
29	3.01	2.99	2.46	2.75	2.34	3.13	3.22	2.66	3.20	2.55	2.8292	0.32
30	2.91	3.24	3.44	3.22	3.65	3.99	3.65	3.27	3.25	3.54	3.4158	0.30
31	2.29	2.66	2.49	2.66	2.88	3.65	3.02	2.15	2.33	3.27	2.7394	0.47
32	2.02	1.75	2.72	1.02	2.36	1.85	2.33	2.33	1.45	1.99	1.9822	0.49
33	3.09	2.72	2.33	3.22	2.66	3.27	2.55	3.66	2.66	3.65	2.9802	0.46
34	2.55	2.83	2.44	2.97	2.55	3.24	2.66	3.66	2.33	2.55	2.7754	0.41
35	2.44	2.44	2.25	3.11	3.25	2.12	2.37	2.97	3.22	3.67	2.7834	0.52
36	2.49	2.24	1.71	1.25	1.37	2.12	2.33	2.37	1.52	1.77	1.9166	0.45
37	1.44	2.30	2.30	2.51	1.25	2.33	2.35	1.99	2.45	2.46	2.1382	0.44
38	2.78	2.06	2.33	2.10	2.00	1.99	2.15	1.23	1.66	2.54	2.0850	0.43
39	2.33	2.49	2.38	2.36	1.99	2.66	2.45	1.75	1.56	2.33	2.2292	0.35
40	2.70	2.88	2.56	2.66	1.97	2.66	2.66	2.11	1.66	2.55	2.4396	0.39
41	1.36	2.03	1.72	1.55	2.12	1.45	2.14	1.55	1.33	1.23	1.6479	0.34
42	1.59	1.73	1.72	1.66	2.00	1.43	1.02	1.55	1.06	1.72	1.5472	0.30
43	1.84	2.05	1.74	1.63	2.00	1.86	1.12	1.43	1.99	2.00	1.7659	0.30
44	1.49	1.56	1.78	1.33	1.65	1.99	2.00	1.23	1.00	1.37	1.5399	0.32
45	2.11	1.81	1.95	1.33	1.49	1.22	1.67	1.10	1.66	1.90	1.6231	0.33
46	1.30	1.33	1.39	1.21	1.57	1.11	0.99	0.55	1.11	1.36	1.1917	0.28
47	1.58	0.85	0.83	1.23	0.23	0.85	0.79	1.22	1.13	0.96	0.9661	0.36
										Mean	*3.0832*	*0.44*

Table D-5a the brightness matching experimental data of subject WU at condition 5 lux illumination.

No.	1	2	3	4	5	6	7	8	9	10	Average	Stnd Div
1	0.67	0.49	0.53	0.67	0.53	0.59	0.53	0.77	0.45	0.23	0.55	0.15
2	1.09	1.51	1.56	1.33	1.55	1.65	1.33	1.43	1.00	0.85	1.33	0.27
3	0.63	1.13	1.05	1.03	0.87	0.76	1.26	1.15	0.99	0.88	0.98	0.19
4	1.24	1.67	0.64	1.11	1.43	1.13	0.87	1.25	0.90	1.65	1.19	0.33
5	1.14	1.34	1.22	0.87	1.33	1.33	1.43	0.99	1.02	0.99	1.17	0.19
6	0.99	0.56	0.75	0.76	0.99	1.07	0.99	0.76	0.87	0.99	0.87	0.16
7	0.47	0.45	0.51	0.51	0.66	0.76	0.76	0.83	0.66	0.86	0.64	0.15
8	0.55	0.45	0.58	0.32	0.46	0.55	0.45	0.59	0.49	0.30	0.47	0.10
9	0.46	0.69	0.64	0.87	0.86	0.97	0.76	0.66	0.55	0.46	0.69	0.17
10	0.57	1.04	0.99	1.02	1.13	0.99	1.33	1.10	0.99	0.90	1.01	0.19
11	1.46	1.37	1.33	1.56	1.37	1.35	1.58	1.24	0.97	1.42	1.36	0.17
12	0.46	0.53	0.50	0.59	0.53	0.77	0.66	0.30	0.57	0.60	0.55	0.12
13	0.68	0.35	0.57	0.35	0.33	0.43	0.43	0.76	0.55	0.68	0.51	0.16
14	0.35	0.57	0.59	0.35	0.33	0.43	0.33	0.35	0.57	0.59	0.45	0.12
15	0.59	1.52	1.10	1.10	1.22	1.32	1.43	1.00	1.43	1.23	1.20	0.27
16	0.61	0.65	1.03	1.33	1.03	1.32	1.32	0.99	1.11	0.99	1.04	0.26
17	0.71	0.76	0.46	0.77	0.87	0.97	0.66	0.71	0.77	0.76	0.74	0.13
18	0.92	0.74	0.61	0.63	0.61	0.74	0.53	0.65	0.45	0.43	0.63	0.15
19	0.61	0.40	0.56	0.33	0.40	0.61	0.43	0.46	0.56	0.37	0.47	0.11
20	0.48	0.43	0.61	0.79	0.87	0.77	0.76	0.61	0.77	0.63	0.67	0.14
21	1.24	0.92	1.10	1.10	0.92	1.10	1.13	0.97	1.13	1.10	1.07	0.10
22	0.82	0.76	1.02	0.87	0.82	0.74	0.57	0.77	0.97	0.68	0.80	0.13
23	0.49	0.69	0.73	0.69	0.47	0.37	0.45	0.77	0.89	0.75	0.63	0.17
24	0.59	0.45	0.64	0.45	0.64	0.45	0.37	0.66	0.37	0.47	0.51	0.11
25	0.96	0.65	0.79	0.99	1.02	0.97	0.96	0.65	0.79	1.25	0.90	0.18
26	0.89	0.93	0.82	0.96	0.83	0.97	0.76	0.76	0.96	0.82	0.87	0.08
27	0.63	0.70	0.77	0.77	0.70	0.87	0.99	0.77	0.76	0.63	0.76	0.11
28	0.57	0.68	0.80	0.56	0.53	0.42	0.40	0.66	0.46	0.42	0.55	0.13
29	0.77	0.77	0.51	0.51	0.58	0.51	0.77	0.51	0.63	0.43	0.60	0.13
30	1.01	0.64	0.92	0.97	0.87	0.57	0.66	0.66	0.66	0.97	0.79	0.17
31	0.62	0.42	0.42	0.78	0.46	0.42	0.61	0.62	0.42	0.55	0.53	0.12
32	0.42	0.31	0.46	0.44	0.31	0.31	0.34	0.46	0.47	0.42	0.39	0.07
33	0.50	0.76	0.65	0.63	0.76	0.65	0.43	0.47	0.65	0.63	0.61	0.11
34	0.50	0.73	0.76	0.77	0.47	0.76	0.43	0.77	0.46	0.47	0.61	0.16
35	0.63	0.58	0.65	0.66	0.63	0.64	0.64	0.54	0.52	0.63	0.61	0.05
36	0.39	0.43	0.50	0.31	0.43	0.43	0.37	0.42	0.37	0.46	0.41	0.05
37	0.44	0.39	0.59	0.55	0.34	0.44	0.39	0.24	0.43	0.33	0.41	0.10
38	0.62	0.69	0.82	0.63	0.84	0.45	0.66	0.33	0.75	0.66	0.64	0.16
39	0.43	0.73	0.72	0.55	0.63	0.73	0.43	0.46	0.77	0.66	0.61	0.13
40	0.55	0.76	0.73	0.77	0.56	0.55	0.76	0.47	0.65	0.54	0.63	0.11
41	0.47	0.56	0.47	0.43	0.47	0.56	0.47	0.56	0.58	0.47	0.51	0.05
42	0.92	0.76	0.64	0.87	0.66	0.65	0.75	0.65	0.90	0.81	0.76	0.11
43	0.67	0.85	0.47	0.42	0.37	0.45	0.57	0.57	0.85	0.77	0.60	0.18
44	0.53	0.65	0.44	0.46	0.43	0.48	0.47	0.49	0.57	0.46	0.50	0.07
45	0.31	0.63	0.70	0.36	0.31	0.45	0.46	0.63	0.47	0.71	0.50	0.16
46	0.71	0.45	0.64	0.45	0.63	0.71	0.47	0.47	0.23	0.46	0.52	0.15
47	0.27	0.34	0.26	0.27	0.34	0.26	0.27	0.37	0.46	0.43	0.33	0.07
										Mean	0.71	0.14

Table D-5b the brightness matching experimental data of subject WU at condition 50lux illumination.

No.	1	2	3	4	5	6	7	8	9	10	Average	Stnd Div
1	4.40	4.85	4.45	4.33	4.01	3.97	4.99	4.88	3.13	4.45	4.34	0.55
2	3.65	3.65	3.80	4.10	3.87	3.22	3.49	3.85	4.03	3.86	3.75	0.26
3	2.52	2.52	1.93	2.77	1.99	2.75	2.46	1.96	2.88	2.76	2.45	0.36
4	3.57	3.02	3.57	3.22	3.04	3.55	2.99	3.99	2.46	3.55	3.29	0.43
5	5.16	6.66	5.60	5.22	6.02	5.32	6.46	5.15	5.75	6.24	5.76	0.56
6	3.52	2.54	2.54	2.88	3.41	3.14	2.89	3.49	2.55	3.21	3.02	0.39
7	3.84	3.05	5.63	4.00	3.02	3.02	2.32	2.24	3.25	3.01	3.34	0.98
8	1.69	2.45	2.58	2.75	1.99	2.51	2.30	1.83	2.02	1.96	2.21	0.36
9	2.70	3.29	2.43	3.42	2.51	2.75	3.03	2.85	2.13	2.13	2.72	0.44
10	5.47	7.30	5.58	6.21	7.13	5.33	6.21	5.21	6.32	5.85	6.06	0.72
11	8.55	8.26	9.76	8.63	9.10	8.37	9.22	8.13	9.26	8.65	8.79	0.52
12	3.94	3.04	4.53	4.63	3.45	4.33	3.85	5.33	2.15	3.63	3.89	0.90
13	3.10	2.69	2.30	2.33	3.01	2.76	2.10	2.75	2.14	3.05	2.62	0.38
14	1.96	2.69	2.30	2.01	2.26	1.99	2.45	2.69	2.30	2.01	2.26	0.28
15	4.27	6.14	6.35	5.56	6.25	5.99	6.32	6.25	5.26	5.25	5.77	0.68
16	6.98	5.91	4.47	5.88	6.97	5.45	6.23	5.22	6.33	5.99	5.94	0.77
17	4.25	3.31	3.08	4.33	3.54	3.02	4.63	4.25	3.46	4.00	3.79	0.57
18	3.36	2.84	2.59	3.46	2.99	2.75	2.97	3.55	2.88	3.57	3.09	0.36
19	1.98	2.03	2.00	2.57	2.01	2.45	1.70	3.25	1.75	2.02	2.18	0.46
20	3.07	3.37	3.03	3.45	2.97	4.01	3.42	3.21	3.54	3.00	3.31	0.32
21	4.21	3.66	4.85	3.25	4.20	3.66	4.75	3.87	4.25	3.49	4.02	0.53
22	3.10	2.72	3.83	3.00	3.15	2.88	3.55	2.88	2.37	3.45	3.09	0.43
23	3.56	2.73	3.01	3.26	2.86	3.05	2.46	3.25	2.85	3.45	3.05	0.34
24	1.29	1.12	1.21	1.33	1.22	1.54	1.00	1.32	0.96	1.12	1.21	0.17
25	5.77	4.60	5.25	4.97	4.22	5.26	4.12	5.22	4.70	4.13	4.82	0.56
26	6.05	5.91	6.42	5.23	6.04	5.99	5.77	6.21	6.05	5.66	5.93	0.33
27	3.65	4.40	4.11	3.88	3.97	4.22	4.10	3.64	4.32	3.43	3.97	0.32
28	2.99	2.95	3.64	3.63	2.45	3.70	3.45	3.12	2.99	3.42	3.24	0.40
29	5.50	6.75	5.66	6.45	5.42	6.37	5.27	5.55	6.24	5.22	5.84	0.55
30	3.33	3.89	2.94	3.44	3.25	2.97	3.03	4.23	4.00	3.46	3.45	0.45
31	3.89	5.51	4.50	5.55	4.69	5.24	4.66	5.63	4.24	3.76	4.77	0.69
32	3.51	2.97	3.87	3.27	2.66	3.43	2.66	3.66	3.76	2.57	3.23	0.49
33	3.63	3.28	3.13	3.10	3.13	2.66	3.63	4.02	2.70	3.75	3.30	0.45
34	1.92	2.64	2.51	1.97	2.04	1.97	2.45	1.63	1.66	2.65	2.14	0.39
35	3.69	3.50	4.21	4.23	4.10	3.65	3.37	4.37	3.65	4.21	3.90	0.36
36	3.58	4.31	3.49	3.58	4.33	4.00	3.66	3.99	3.79	3.46	3.82	0.32
37	6.09	6.03	7.30	6.05	6.33	3.66	3.66	4.66	2.33	2.37	4.85	1.76
38	2.22	3.56	3.97	2.20	2.33	2.36	2.02	3.66	3.42	3.02	2.88	0.73
39	4.01	4.93	4.55	4.63	5.27	3.97	4.33	5.03	4.22	3.66	4.46	0.51
40	4.55	4.21	4.45	3.33	3.97	4.03	3.69	4.05	5.22	3.96	4.15	0.51
41	2.61	3.29	2.27	2.21	3.33	2.53	2.63	3.65	3.13	2.34	2.80	0.51
42	1.41	1.37	1.37	1.63	1.33	1.43	1.53	1.68	2.07	2.00	1.58	0.26
43	3.97	4.03	3.89	3.99	4.12	4.10	3.97	3.01	4.06	4.13	3.92	0.33
44	1.88	1.45	2.00	2.00	1.99	1.88	1.45	1.99	2.10	1.30	1.81	0.29
45	2.32	1.52	1.69	1.83	1.47	2.10	1.76	1.36	1.47	2.00	1.75	0.31
46	1.52	1.69	2.16	2.02	2.10	1.97	1.76	1.86	2.03	1.66	1.88	0.21
47	0.63	0.48	0.51	0.66	0.99	0.75	0.65	0.86	0.75	0.65	0.69	0.15
										Mean	*3.60*	*0.48*

VITA

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