CHAPTER 2

THEORETICAL CONSIDERATIONS AND LITERATURE REVIEW

2.1 Theoretical considerations

2.1.1 The perception of color

Color perception involves three basic factors the source of light, objects under illumination, and the eyes and neural responses of observers. The visual process begins when radiant energy from the source strikes the object and some of this energy is reflected and passes through the lens to strike the retina in the eye. The retina is made up of a complex network of cells and neurons. The retina consists of a large number of cells which are sensitive to light; these receptors cells are of two kinds, rods and cones. Rods are sensitive to brightness of light only at low illuminate. Cones are cells of three different types which respond to red, blue and green regions of light, respectively, and it is through these that all colors are seen. When the three types of cones are all stimulated equally, the eye and the brain see achromatic, but if one type of cone is stimulated more than the other two, the image appears to be tinted with the corresponding primary hue.

The most central part of the retina is called the fovea and it has the largest concentration of cells. The fovea vision is used for distinguishing very fine detail, such as reading and seeing objects at distance. Outside the fovea, the number of cones is greatly reduced and they are situated quite apart from one another. The rods are completely absent from the fovea and fall out to the extreme periphery. The signals leave the retina via the optic nerve and eventually arrive at the back of the brain. The brain signals are interpreted through mental impressions that result in perception.*(3,4)*

2.1.2 The Munsell system

The Munsell system is one of internationally accepted used of all the color order systems. Artist Albert H. Munsell developed this system in 1905. The objective of Munsell was to have both a numerical system and a physical exemplification that have equal visual increments along each of the three perceptual dimensions, achieved via the Atlas of the Munsell Colors. The samples consist of painted paper and are available in both gloss and matte surfaces. Munsell uses the terms of hue, value (lightness) and chroma (saturation) to describe the attributes of color

2.1.2.1 Munsell hue

There are 10 hues arranged in the Munsell system is divided into five principal hues, Purple, Blue, Green, Yellow, and Red, and they are designated 5P, 5B, 5G, 5Y, and 5R, respectively, and five intermediate hues are also designated: 5PB, 5BG, 5GY, 5YR and 5RP, as shown in Finger 2-1 (6). For each of the ten hues, there are ten hues with notations as illustrated by the range between 5P and 5PB and consisting of 6P, 7P, 8P, 9P, 10P, 1PB, 2PB, 3PB, and 4PB. Therefore, there are 100 hue steps in the Munsell circle.

2.1.2.2 Munsell value

There are ten main steps in the Munsell value scale with white given a notation of N10, black a N0, and intermediate grays given notations ranging between N0 and N10, as shown in Figure 2-2 (7). The design of the Munsell value scale is such that an intermediate gray with a Munsell value of 5 is perceptually halfway between white and black. Also, the perceived lightness difference between N3 and N4 samples is equivalent to the lightness difference between N6 and N7 samples or any other samples varying by one step in Munsell value.

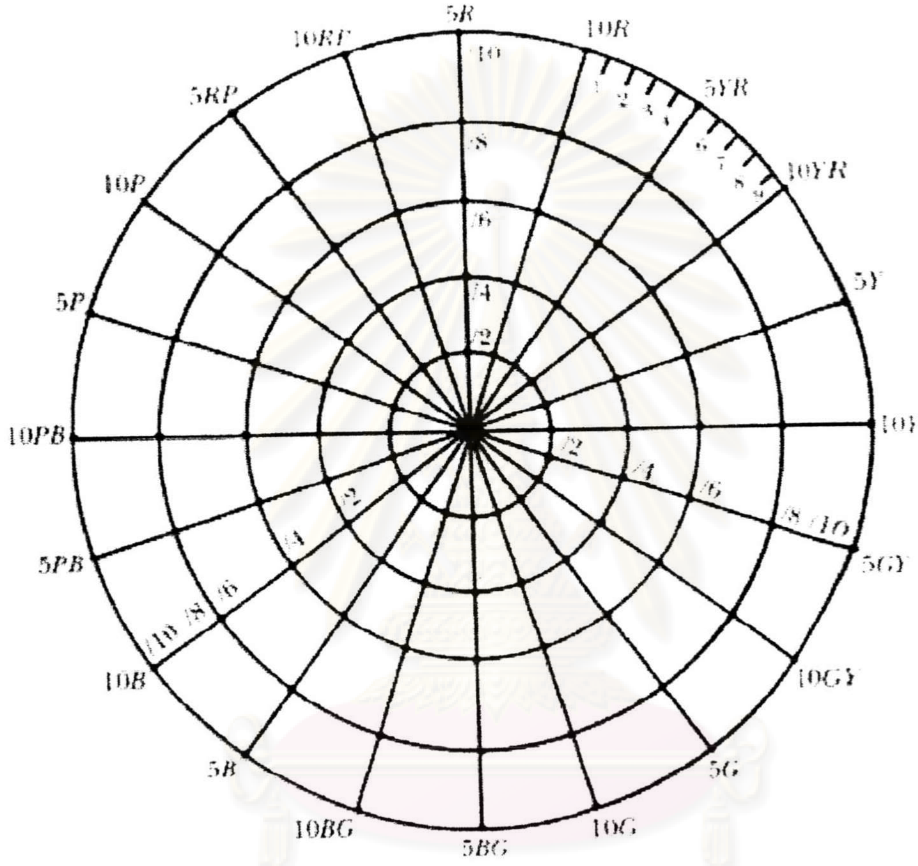

Figure 2-1 Arrangement of hue circle in the Munsell system

2.1.2.3 Munsell chroma

The distance of the sample from the value axis are intended to represent uniform differences in perceived chroma and are given numbers that are typically as small as 4 or less for weak colors, and 10 or more for strong colors. The scales of chroma extends from/0 for a neutral gray out to /10, /12, /14 or father (*8*).

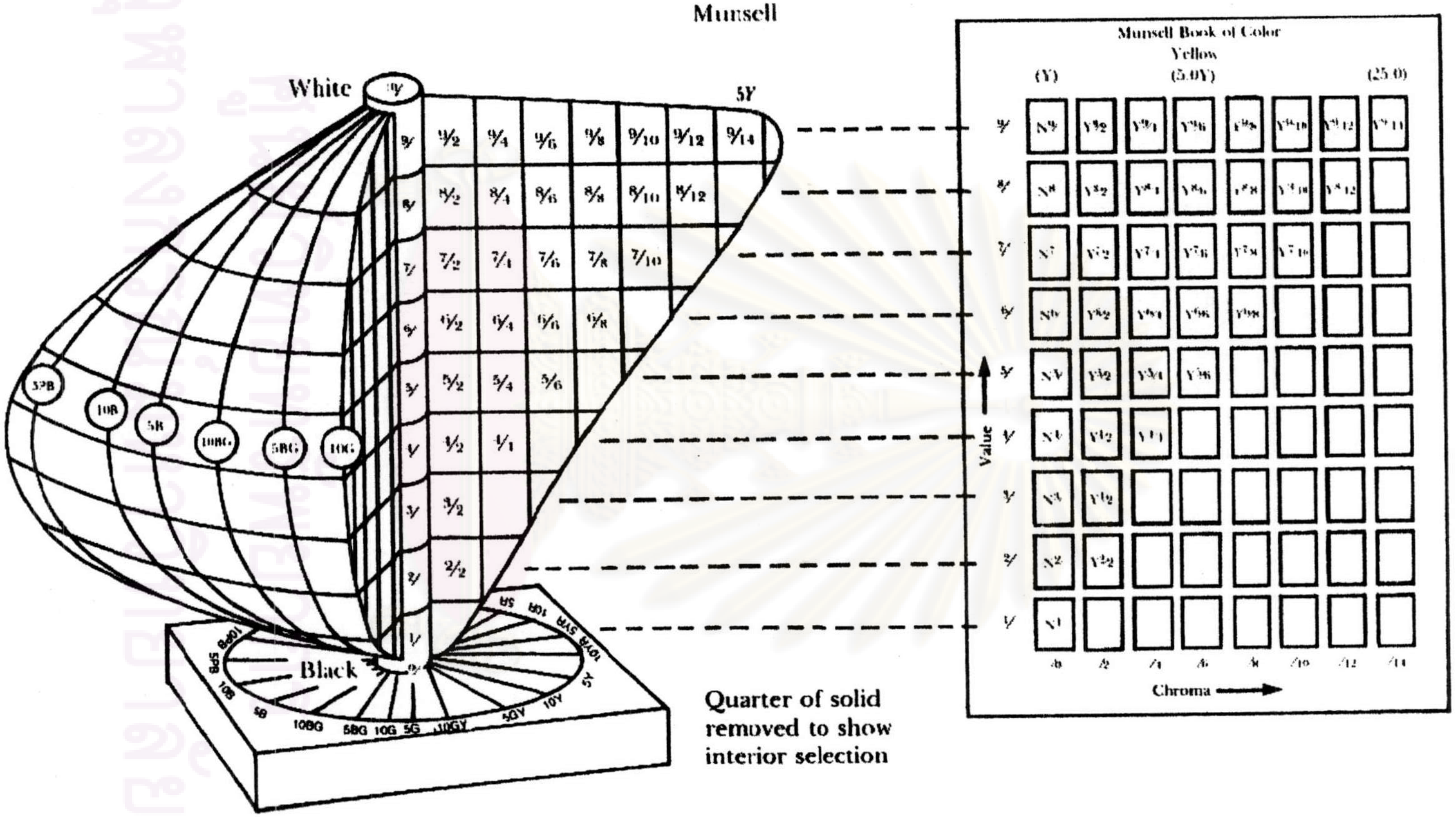

Figure 2-2 The Munsell color space

2.1.3 The CIE color system

In 1931, the CIE (Commission International de l'Eclairage or International Commission on Illumination) developed the standards for description aspects of color specification called colorimetric. The standards of colorimetric to be concerned with the relative spectral distribution of radiant flux emitted by the source and incident on the object, the spectral reflectance factors of the object and the color matching function of the observer viewing the object (*9*). The CIE color system is a system to specify a color appearance quantitatively, is not directly based on psychological scaling of colors like the Munsell color system.

2.1.3.1 CIE illuminants

The CIE has established a number of spectral power distributions as CIE illuminants for colorimetric. These distributions based on physical standards, such as blackbody radiators or Planckian radiator, or are based on statistical representations of measured light.

CIE illuminant A represents a Planckian radiator with a color temperature of 2856 K, as shown in Figure 2-3 (*10*). It is used for colorimetric calculations when incandescent illumination is of interest.

CIE illuminant C is the spectral power distribution of illuminant A as modified by particular liquid filters defined by the CIE. It represents a daylight simulator with a correlated color temperature of 6774 K, as shown in Figure 2-4 (*11*).

CIE illuminants D65 and D50 are part of the CIE D series illuminants that have been statistically defined based upon a large number of measurements of natural daylight. Illuminant D65 represents an average daylight with a correlated color temperature of 6500 K, and D50 represents an average daylight with a correlated color temperature of 5003 K, as shown in Figure 2-4. D65 is commonly used in colorimetric applications, such as paints, plastics, and textiles. D50 is often used in graphic arts and computer industries. CIE D illuminants with other correlated color temperatures can be easily obtained.

CIE F series illuminants represent typical spectral power distributions for various types of fluorescent sources including standard cool white, warm white, "full spectrum," and tri-band, 12 in all. CIE illuminant F2 represents cool white fluorescent with a correlated color temperature of 4230 K. Illuminant F8 represents a fluorescent D50 simulator with a correlated color temperature of 5000 K, and illuminant F11 represents a tri-band fluorescent sources with a correlated color temperature of 4000 K, as shown in Figure 2-5 and in Figure 2-6 (*12*). Tri-band fluorescent sources are popular because of their efficiency, efficacy, and pleasing color-rendering properties.

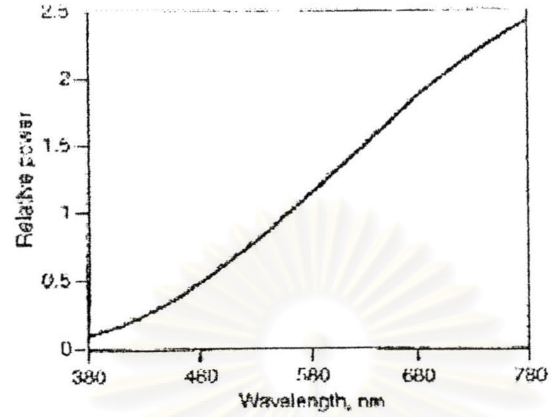

Figure 2-3 The spectral power distribution of CIE illuminant A

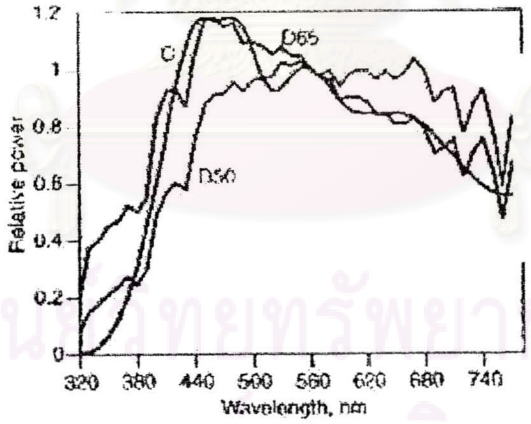

Figure 2-4 The spectral power distribution of CIE illuminants D50, D65 and C

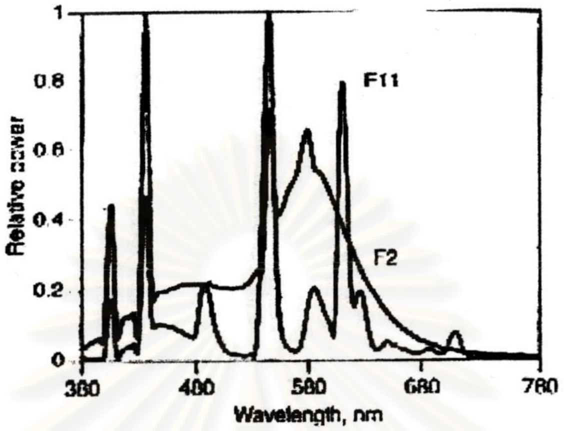

Figure 2-5 The spectral power distribution of CIE illuminant F2 and F11

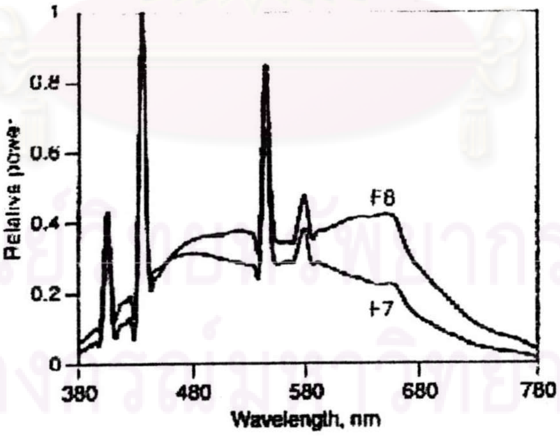

Figure 2-6 The spectral power distribution of CIE illuminants F7 and F8

2.1.3.2 Standard of reflectance factor

The CIE recommends that reflectance measurement should be made relative to the perfect reflecting diffuser. There is no object surface that has the properties of the perfect reflecting diffuser, but working standards of known spectral reflectance factors is normally used. The working standards for reflectance factor measurement are also called white standard. The effect of an object on light can be described by its spectral transmittance or reflectance curve. The spectral reflectance curve describes the object just as the spectral power distribution curve describes a source, as shown in Figure 2-7 (*13*).

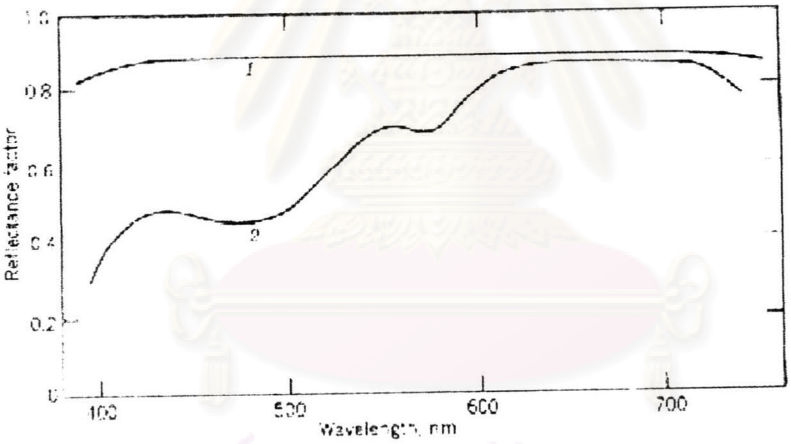

Figure 2-7 The spectral reflectance factor of hypothetical white (1) and tan (2) specimens

2.1.3.3 CIE standard observers

The colorimetric specifications of color based on the spectral tristimulus values of $\bar{x}_{\lambda}$, $\bar{y}_{\lambda}$ *and* $\bar{z}_{\lambda}$ which are also called the color matching functions. There are two sets of color-matching functions established by the CIE. The CIE 1931 standard colorimetric observer was determined from experiments by Guild and Wright, using a visual field that subtended 2 degrees that the matching stimuli were imaged onto the retina completely within the fovea. In 1964, the CIE recommended a set of color-matching functions are notated as $\bar{x}_{10\lambda}$, $\bar{y}_{10\lambda}$ and $\bar{z}_{10\lambda}$, for the experiments using a 10° visual field that excluded the central fovea. The results for large fields were deemed significantly different from the 2° standard, enough to warrant the establishment of the CIE 1964 supplementary standard colorimetric observer, sometimes called the 10° observer, as shown in Figure 2-8 (*14*). Nowadays standards exist for two field sizes, 2° and 10°.

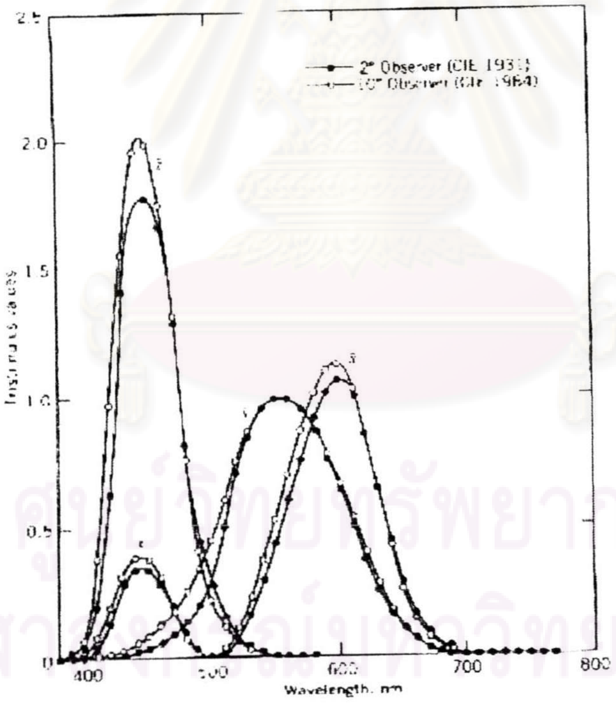

Figure 2-8 Comparison of color matching functions of the 1931 CIE standard observers and the 1964 CIE supplementary observers

2.1.3.4 CIE XYZ tristimulus values

The CIE tristimulus values X, Y, and Z of color are obtained by multiplying together the relative power of a CIE standard illuminant, the reflectance factor or the transmittance of the object and the standard observer function, as shown in Figure 2-9 (*15*), by the equations as below:

$$X = k\sum S_\lambda R_\lambda \bar{x}_\lambda \Delta\lambda$$

$$Y = k\sum S_\lambda R_\lambda \bar{y}_\lambda \Delta\lambda$$

$$Z = k\sum S_\lambda R_\lambda \bar{z}_\lambda \Delta\lambda$$

$$k = 100 / \sum S_\lambda \bar{y}_\lambda \Delta\lambda \qquad (2.1)$$

Where, S_λ	is the spectral power distribution of light illuminant or source
R_λ	is the spectral reflectance factor of object
$\bar{x}_\lambda$, $\bar{y}_\lambda$ and $\bar{z}_\lambda$	are the color matching functions
k	is a normalizing constant
$\Delta\lambda$	is the measurement wavelength interval
Σ_λ	is summation across wavelength

By convention, the value Y = 100, assigned to perfect white object reflecting 100% at all wavelengths, or to the perfect colorless sample transmitting 100% at all wavelengths, is the maximum value that Y can have for non fluorescent sample.

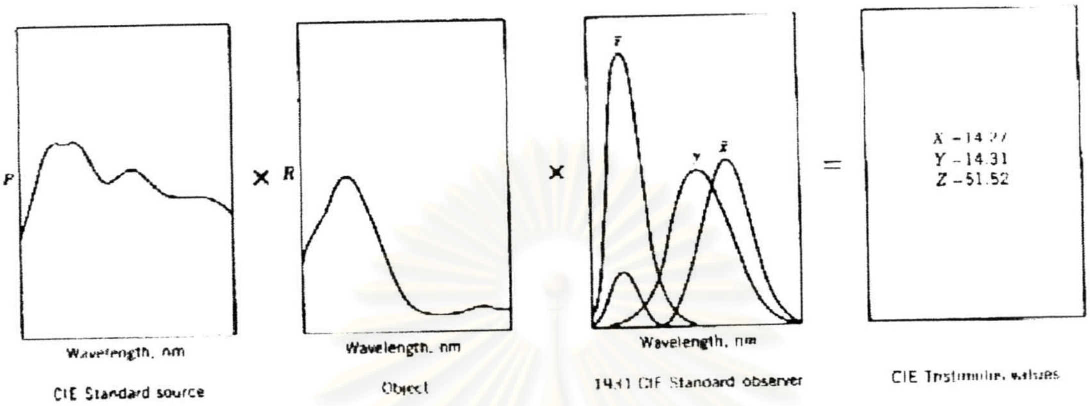

Figure 2-9 The CIE tristimulus values X, Y and Z of color

2.1.4 The CIE L* a* b* color space, The CIE LUV color space, The CIE L* C* h color space

The limitation of the CIE system is its non-uniformity. Equal changes in x, y or Y do not correspond to equal visual differences. Many attempts provided a more uniform system. The end result is CIEL L* a* b* 1976 color space that for the measurement of color differences. This space extends tristimulus colorimetry to three-dimensional space with dimensions that approximately correlate with the perceived lightness, chroma and hue of a stimulus.

The variables used in the CIE L* a* b* system are L* as the correlate of lightness, a* as the correlate of redness or greenness, and b* as the correlate of yellowness or blueness, as shown in Figure 2-10 (*16*), are defined as follow.

$$L^* = 116(Y/Y_n)^{1/3} - 16$$

$$a^* = 500[(X/X_n)^{1/3} - (Y/Y_n)^{1/3}]$$

$$b^* = 200[(Y/Y_n)^{1/3} - (Z/Z_n)^{1/3}]$$

$$C^* = (a^{*2} + b^{*2})^{1/2}$$

$$h = \tan^{-1}(b^*/a^*) \tag{2.2}$$

where, X/X_n, Y/Y_n, Z/Z_n, > 0.008856

X, Y and Z	are	the tristimulus values of the stimulus
X_n, Y_n and Z_0	are	the tristimulus values of the reference white
C*	is	chroma
h	is	hue angle

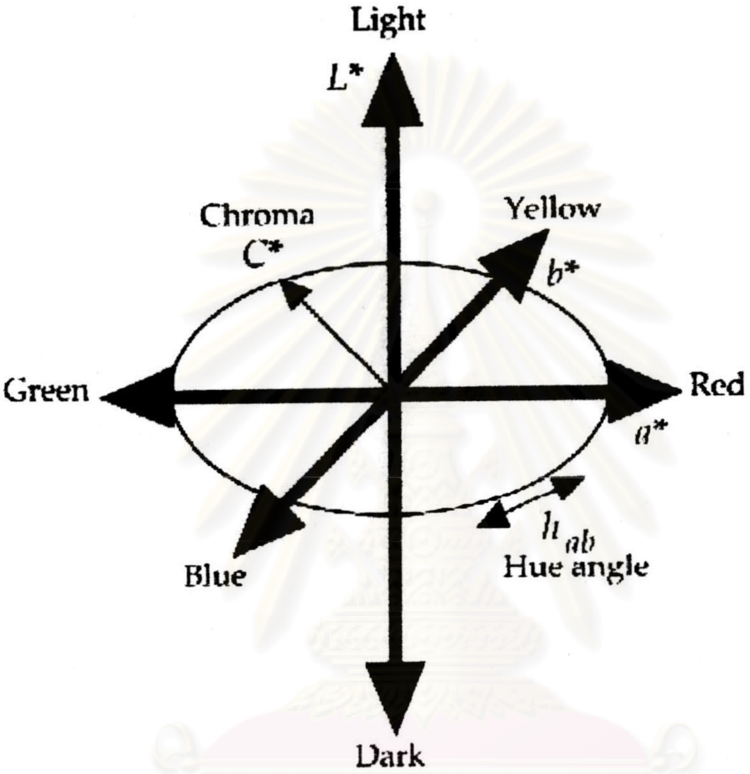

Figure 2-10 The cylindrical representation of the CIE L* a* b*(CIE L* C* h)

2.2 Literature reviews

2.2.1 Color naming system

Colour tone systems such as ISCC-NBS and PCCS systems as shown in Figure 2-11*(17)* and 2-12*(18)* are useful to simply communicate the tone of a colour. The iso-hue planes of the colour tone systems are divided by colour tone words such as vivid, deep and pale. But the colour tone systems do not numerically correspond to Munsell and CIE L* a* b* colour order systems, and each tone of the colour tone systems is not directly calculated from colorimetric values measured using a spectrophotometer. For example, vivid yellow, vivid red and vivid blue do not have the same lightness and chroma on the Munsell and CIE L* a* b* systems, but these colours are described as the same colour tone. Even if colour tones in the colour tone systems are the same, the coordinates of the colour tones on an iso-hue diagram such as Munsell V-C and CIE L* C* diagrams are different. This means the attributes of the colour tone systems are different values from lightness and chroma.

If colour tones are numerically expressed, it will be more useful to communicate them and more helpful for colour planning. Therefore, a colour tone system calculated from colorimetric values through colour measurement has been developed. In the colour tone system, colour tones are instrumentally assessed through colorimetric values measured using a spectrophotometer. The iso-hue plane of the colour tone system is divided by colour depth and modified chromatic values.

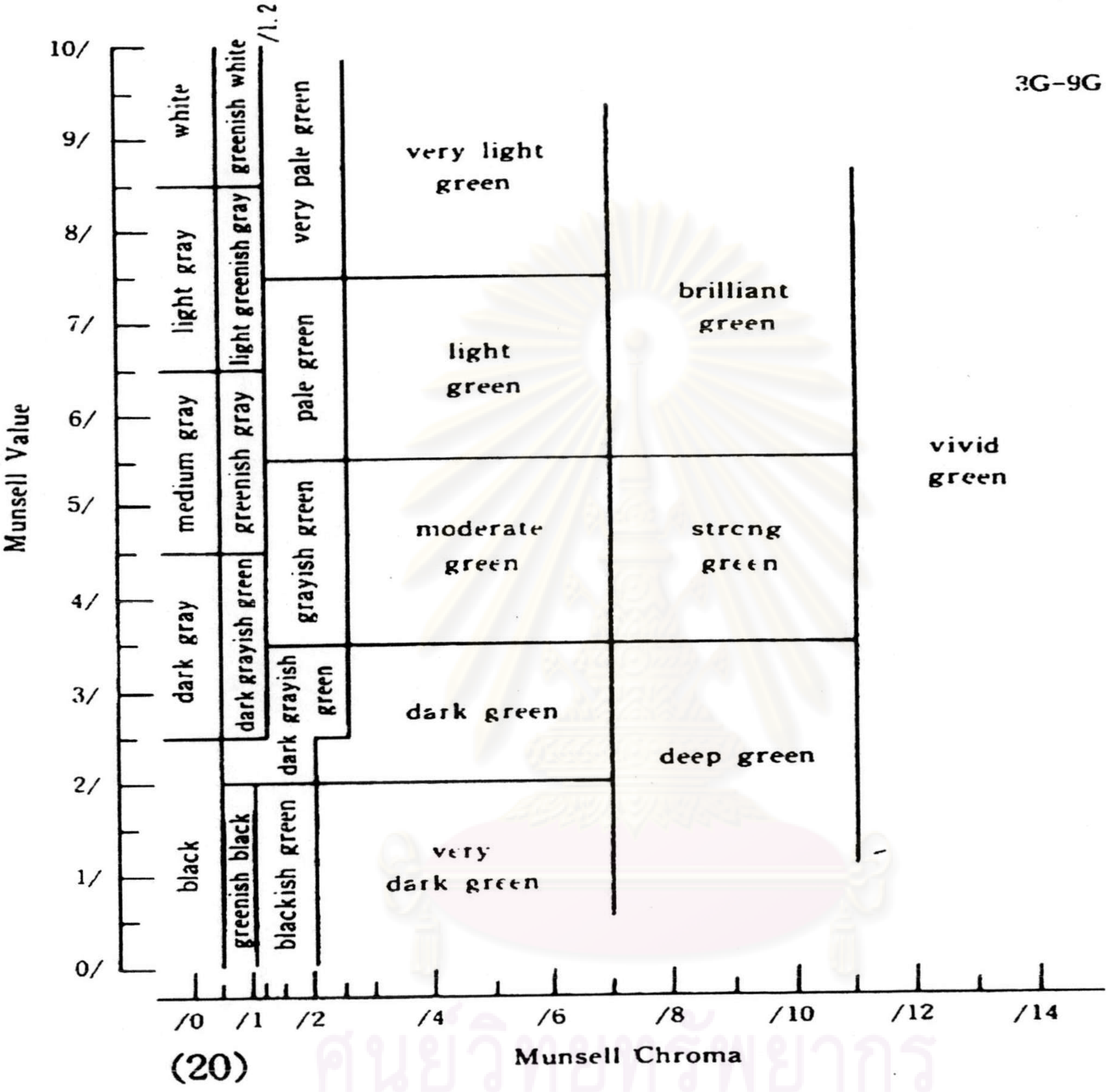

Figure 2-11 ISCC-NBS centroid color chart (1958)

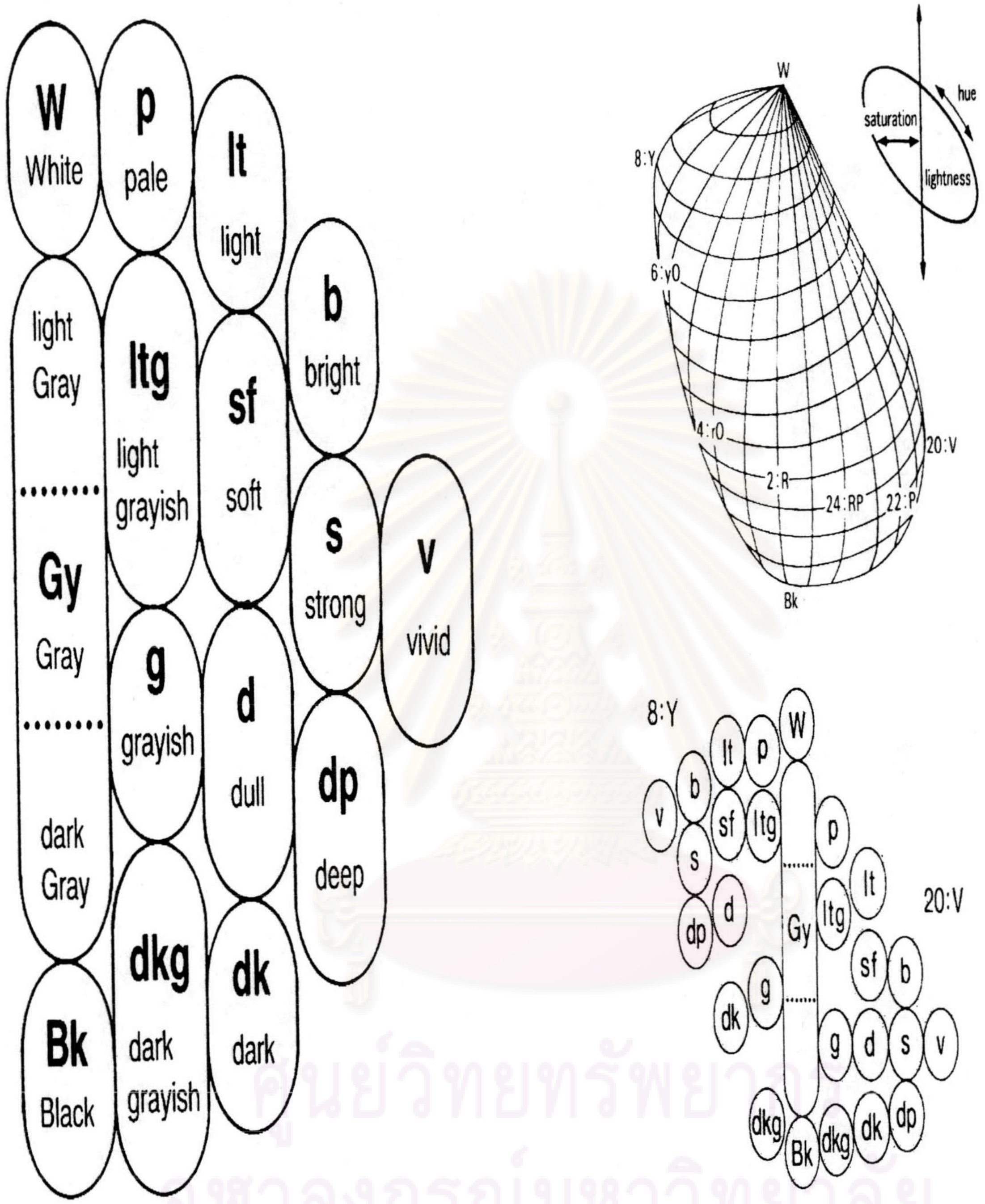

Figure 2-12 PCCS: Practical color co-ordinate system (Y-V) (1960)

2.2.2 Color naming model.

Lin et al. *(19)* A color-naming model was developed to categorize volumes for each of the 11 basic names in CIE L* a* b* color space. This was tested with three different sets of data for two languages (English and Mandarin), derived from extensive color categorization experiments. The performance of the model in predicting color names was satisfactory, with an average prediction error of 8.35

Nakamura et al.*(20)* Taking the recent development of colorimeter and computer into consideration, they hold that in the area of color, too, it is necessary to deal with colors quantitatively, not depending on individual's sense, by transforming colors. into numerical expressions with use to colorimeter and to establish a scientific system of colors. Choosing a color depends greatly on individual's sense, but they expect that our sense will also be further refined by utilizing such as scientific system of colors.

Thereupon in establishing a scientific system of colors, they have tried to correlate colorimetric values with image words of common use.

Systematic specimens were produced, visual judgement experiments were conducted, and based on their results, word for color perception were arranged in a color solid which deals with color quantitatively.

If a color is measured in this manner, they can learn the color image that color has, and conversely, it is possible to find out a color corresponding to the particular image word immediately. For that reason, they regard that this scientific system of colors can be put greatly to practical use such as color scheme.

Siripant *(21)* His research are to made scientific system color value of mural into Munsell color space for made it to be standardize color model.

Engchuan *(22)* This study is to analyze the basic color terms, the boundaries and foci of basic color categories, the change in color categorization and concept, as well as the non-basic color terms in the Sukhothai period and at the present time.

2.2.3 Quantitative scale

Ngampatipatpong et al. *(23)* derived the quantitative visual scale of the word which express human emotion by using the opponent word pair and relevant to calorimetric values. The experiment establishes color emotion scale of Thai observers, which relates to its lightness and chroma.

Sato et al. *(24)* used the numerical expression of color emotion to find the instrumentally assessment. The twenty-four color emotion formulae based on the Munsell and CIE L* a* b* color systems were derived. The characteristic of color emotion simulated through the above formulae was indicated as color emotion lines in Munsell color system and the color emotion map was developed.

As mentioned above, color study must be conducted in the pure scientific manner. This was confirmed by the evidences from the past studies that their studies were heavily dealt with the estimation of technical color value in which various scientific tool were utilized.

Above all, our literature survey pointed out that no study has ever been made on colors in conjunction with analysis on a language used (Thai words for color perception). Moreover the study on the interdisciplinary basis which is believed to give important information for breaking through in understanding the colors has also never been found in the record.