CHAPTER 2

THEORETICAL CONSIDERATIONS AND LITERATURE REVIEW

2.1 Theoretical Considerations

Color is not purely physic, physiology or psychology but the combination of them as shown in Figure 2-1 (*8*). Color is the reproduction of seeing. That is the result of the physical modification of evaluation the radiant energy, physiological correlation with the perceptual process in the retina, which observed by the human eye, and psychological of interpretation in the brain. Therefore, the production of color consists of three factors, which are source of light, object that its illuminates, and the eye and brains to received the color. (*9*)

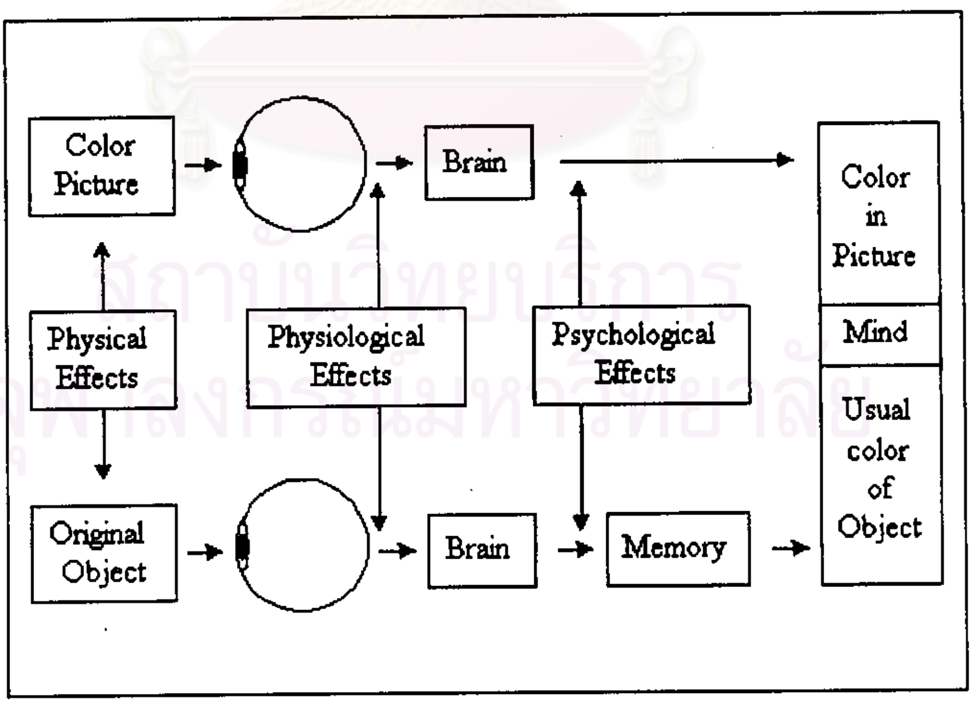

Figure 2-1 Diagrammatic process of the human color perception.

Perceiving of color depends on the wavelength of the light. It is the electromagnetic radiation having a wide range of continuous wavelength; however, only wavelengths ranging from 380 to 760 nanometers are able to stimulate the visual system of human and known as the visible spectrum. In visual process, the eyes act as a transducer converting the electromagnetic energy of light into nerve impulses. As light reaches the eyes, it is refracted at cornea, the transparent outer layer of the eye, and enters the eye through pupil, the circular aperture. Iris at the pupil controls the amount of light entering the eyes by dilating under bright light and constricting in the dark. For Asians, the pupil is black because most of the visible light entering the eye is absorbed. Acute vision depends on the ciliary muscle that acts on shape of lens to focus shape of the image in the center of retina, fovea. Light is absorbed by layer of cells containing melanin pigment, photosensitive pigments, on the back of the retina. The retina contains the photoreceptors, which are rods and cones. The photoreceptors translate the light to electrical signals and the signals are transmitted across synapse, junctions between nerve cells, to the connection layer of bipolar cells. Here, information from clusters of receptors are collated and transmitted to the next layer called ganglion cells. Fibers form the ganglion cells all over the inside of the eye converges on the head of the optic nerve that marks their exit to the brain (*10, 11*).

Not only the pathway of human color perception is extremely complicated and not completely understood, but also the mechanism for interpretation in human brain is still not well comprehend. Furthermore, the psychology factors such as experience, knowledge and attitude are uncontrollable. Thus, it is difficult to communicate about color. In order to obtain the effective the color communication, it is necessary to study about color order system. This thesis considers only the Munsell System and the CIE system (*12-14*).

2.1.1 *The Munsell System*

The Munsell System is one of the most widely used color orders systems. A.H. Munsell, an artist, originated the conceptual structure of the Munsell system in 1905. After that, it was extend and refined in various ways by Nickerson since 1976. The important feature of the Munsell system is that the color is arrange as nearly as possible and the intervals of the visual perception between two neighboring samples are equal. For this reason, the perceptual difference between any adjacent samples is constant.

The Munsell system is both of the collection of the painted samples, and the system for describing all possible color in terms of its three coordinates, Munsell Hue, Munsell Value and Munsell Chroma. These coordinates correspond to three variables commonly used to describe color, which are hue, value and chroma, respectively. Colors are arranged in three-dimensional cylindrical form as shown in Figure 2-2 (*15*). The color samples in the Munsell Book usually arrange in plane or pages of constant hue. On each page, the color samples are arranged by Munsell Value along the vertical direction and by Munsell Chroma along the horizontal direction.

2.1.1.1 <u>Munsell Hue</u>

Hue is that quality of color described by the words red, yellow, green, blue and so on. The spacing of the hue around the grey scale represent the uniform difference of perceived hue between neighboring hue pages. There are five principal hues, Red, Yellow, Green, Blue and Purple, and they are designated 5R, 5Y, 5G, 5B and 5P, respectively. The intermediate hues are designated 5YR, 5GY, 5GB, 5PB and 5RP. Finer divisions between any two major neighboring hues are represented by decimals, as shown in Figure 2-3 (*16*). There are ten major hues ranging in the hue circle. Each of the ten is divided into 10 hue steps. Thus, the Munsell system contains totally 100 hues.

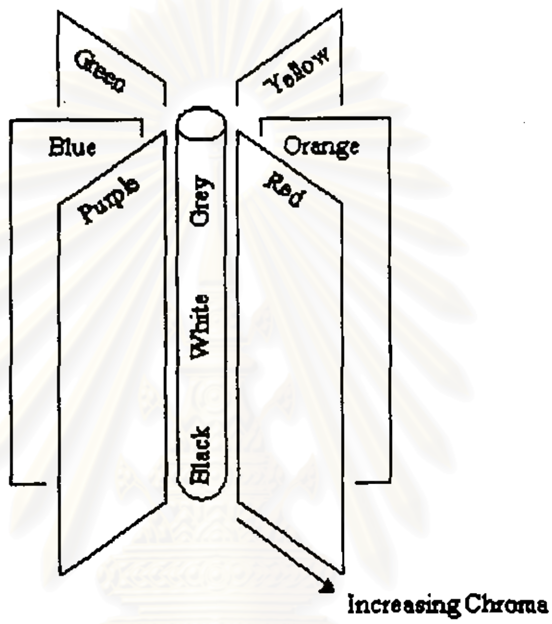

Figure 2-2 Three-dimensional array of hue, value and chroma.

2.1.1.2 Munsell Value

Munsell Value, representing the lightness scale, is arranged in the vertical direction or the backbone of the Munsell system. Value is that quality by which a color can be classified as equivalent in lightness to some member of the series of gray samples ranging from white to black. It is denoted 10/ when white and 0/ when black. From decimal, there are 9 gray concentrations uniformly locating in between black and white and designating the values, as shown in Figure 2-4 (*17*). For example, a value of 7.5 is perceptually midway in lightness between sample having value of 7 and 8.

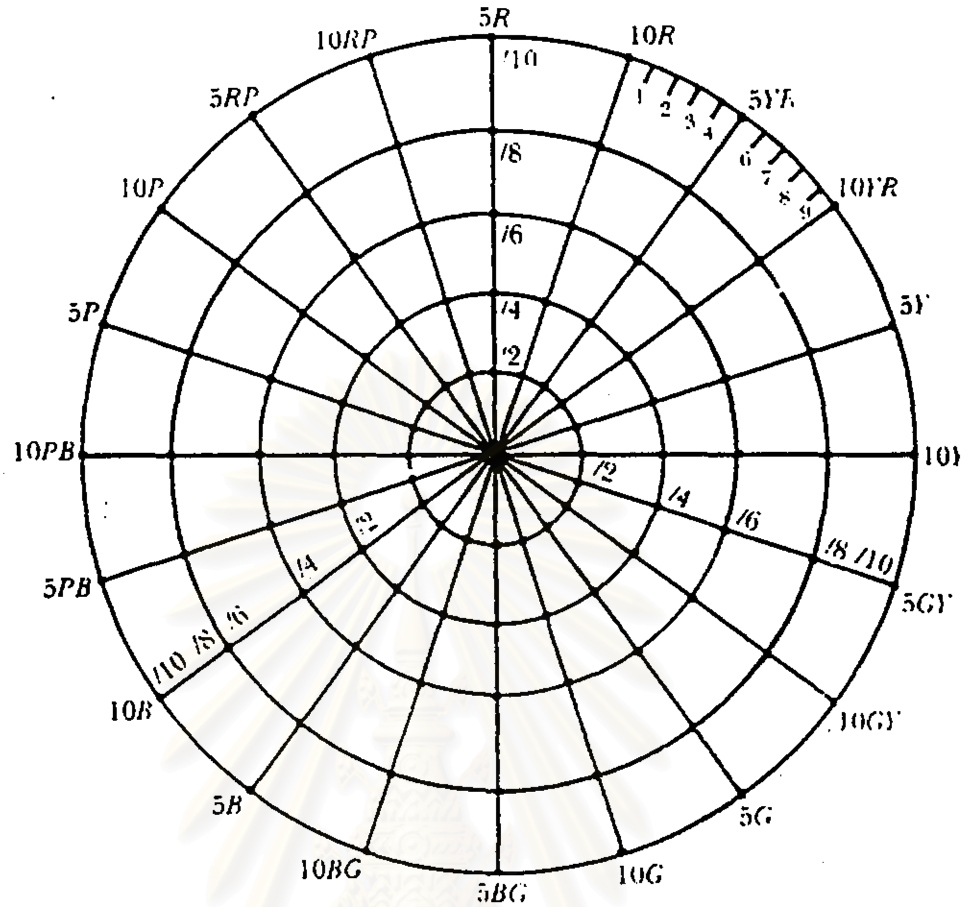

Figure 2-3 Arrangement of Hue circle in the Munsell system.

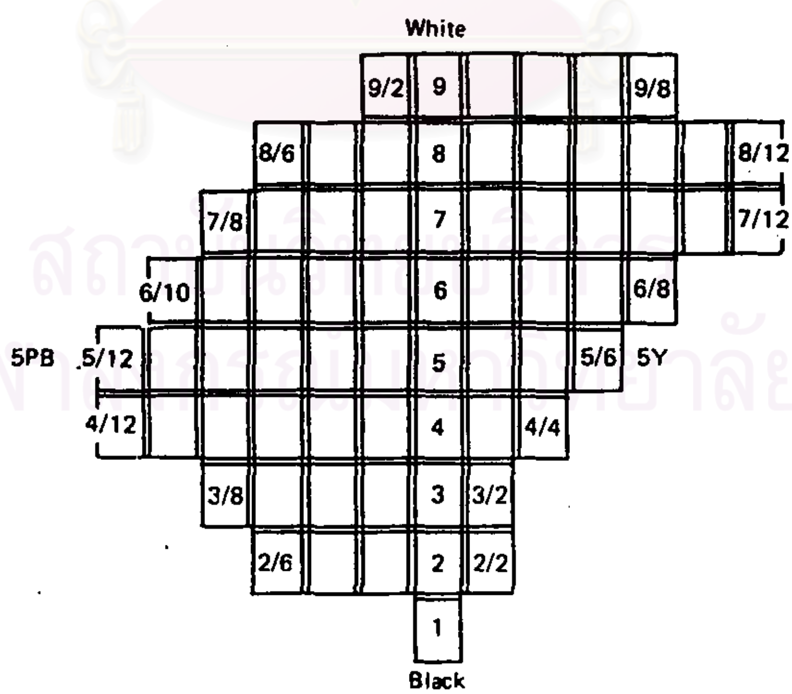

Figure 2-4 Arrangement Value of color of constant Hue in the Munsell System.

2.1.1.3 Munsell Chroma

Chroma is the quality that describes the degree of difference between a color and a gray of the same value or lightness. The distances of the samples from value axis are intended to represent uniform differences in perceived chroma and are given numbers. Typically, number 4 or less represents weak color, and number 10 or more stands for strong color. The scale of chroma increases in step of 2 from /0, /2, /4, so on until it reaches /10, /12, /14 and more.

2.1.2 *The CIE System*

The CIE system is also an important system, which 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 the international committee, or International Commission on Illumination in 1931. The CIE system starts with the premise developed on the human color perception process that the stimulus for color is provided by the proper combination of a source of light, an object, and an observer.

The fundamental aspects of color in the 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 2-5 (*18*). Unlike the Munsell system, this system is not directly based on psychological scaling of color, but the color quantification.

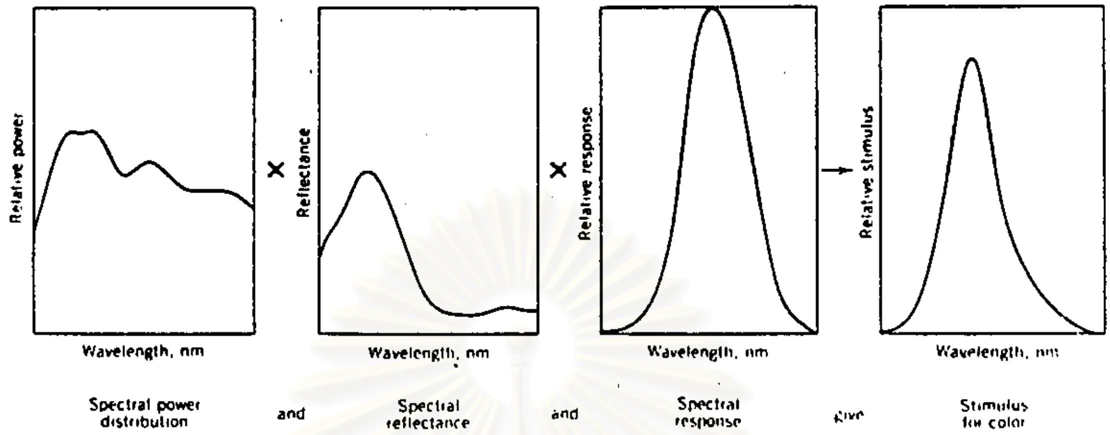

Figure 2-5 The relative stimulus of the brain or instrument interprets as a color

The CIE introduce the element of standardization of source an observer, and the methodology to derive numbers that provide a measure of a color seen under a standard source of illumination by standard observer.

2.1.2.1 <u>CIE Standard Sources and Illuminants</u>

The CIE has introduced some standardization by distinguishes between illuminants, which are defined in terms of spectral power distribution. The sources are defined as physically of radiant power.

- CIE Standard Illuminant A

The most common artificial light source is the tungsten filament lamp. The spectral power distribution of light originated from this source is almost entirely dependent just on the temperature of the filament. The temperature quoted as about 2856 K, is both the distribution temperature and color temperature of tungsten. The relative spectral power distribution of Standard Illuminant A, S_A, is illustrated in Figure 2-6 (*19*).

- CIE Standard Illuminant B

The CIE Standard Illuminant B was intended to simulate direct noon sunlight. It is described by correlated color temperatures of 4874 K. Its distribution, S_B, is shown in Figure 2-6.

- CIE Standard Illuminant C

The CIE Standard Illuminant C was intended to represent an average daylight. It is described by correlated color temperatures of 6774 K. Its distribution, S_C, is shown in Figure 2-6.

- CIE Standard Illuminant D_{65}

The CIE Standard Illuminant D_{65} is base on numerous spectroradiometric measurements of daylight. Its relative spectral power distribution and its correlated color temperatures at 6500 K, is shown in Figure 2-6. Illuminant D_{65} represents a phase of average daylight.

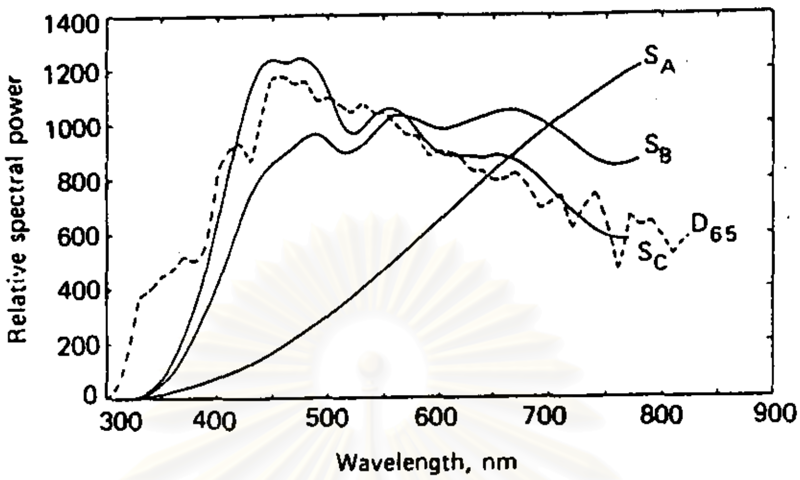

Figure 2-6 Relative spectral power distributions of Standard Illuminants A (S_A), B (S_B), C (S_C) and D_{65}

2.1.2.2 <u>CIE Standard Observers</u>

CIE standard observers are the representatives of the average human population having normal color vision. They can be classified into two groups, the 1931 CIE Standard Observers and the 1964 CIE Supplementary Standard Observers.

The CIE recommends the colorimetric specifications of color, are base on the spectral tristimulus values $\bar{x}(\lambda), \bar{y}(\lambda), \bar{z}(\lambda)$ which are also called the CIE color matching functions for the Standard Colorimetric which were derived from measurement with a 2° visual field by Guild and Wright (*19*). The angle of vision is 2° so the visual takes place only on fovea. The field of view is much narrower than that is normally used for critical color appraisal. However, the variation of the visual field size effects color classification. The CIE recommends another set of color matching functions $\bar{x}_{10}(\lambda), \bar{y}_{10}(\lambda), \bar{z}_{10}(\lambda)$ which have field sized greater than 4°. It is the 1964 CIE Supplementary Standard Observers, which is also called 10° observers. This set gives more accurate correlation with visual color matching. The comparison of color matching functions of the 1931 CIE Standard Observers and the 1964 CIE Supplementary Observers was shown in Figure 2-7 (*21*).

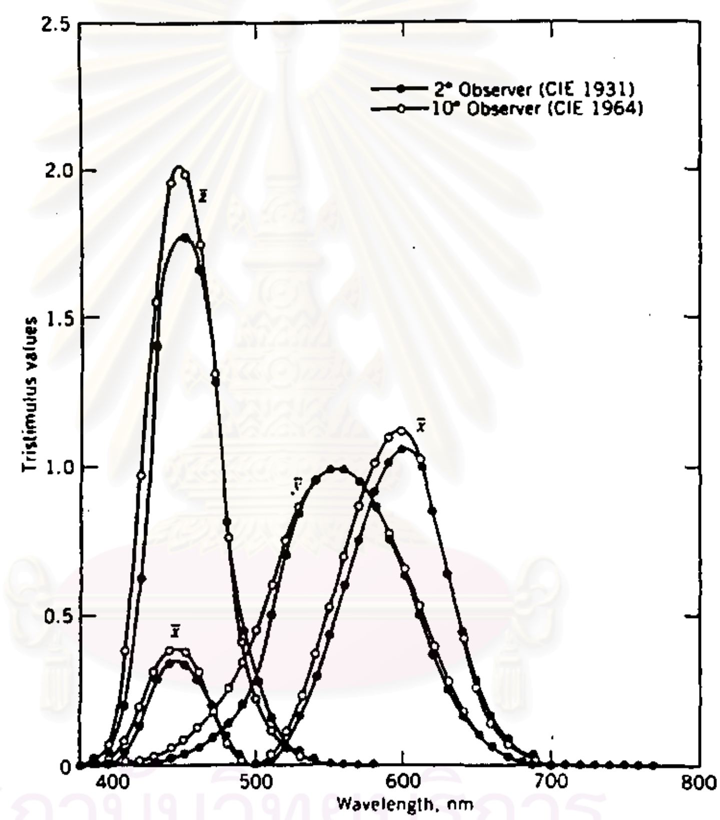

Figure 2-7 Comparison of color matching functions of the 1931 CIE Standard Observers and the 1964 CIE Supplementary Observers.

2.1.2.3 <u>CIELAB color space</u>

The limitation of the CIE system is due to non-uniformity of the changes in *x*, *y* or Y with the corresponding perceived color, that is, equal change of *x*, *y* or Y, do not correspond to the same perceived difference. To quantify color in this system, many color difference formulae have been proposed. One effective formula is the CIELAB equations, which have been developed by the CIE since 1976. These equations are obtained by using L^*, a^* and b^* as mutually perpendicular axes as shown in Figure 2-8 (*22*) where L^*, a^* and b^* are defined as follow:

- The CIELAB equation

$$\begin{aligned} L^* &= 116(Y/Y_n)^{1/3} - 16 \\ a^* &= 500\left[(X/X_n)^{1/3} - (Y/Y_n)^{1/3}\right] \\ b^* &= 200\left[(Y/Y_n)^{1/3} - (Z/Z_n)^{1/3}\right] \end{aligned} \qquad (2.1)$$

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

X_n, Y_n, and Z_n are the tristimulus values. The lightness of the sample is represented by L^* on a scale running from zero for black to 100 for white. The other attributes can be represented on a plot of b^* against a^*. Neutral color plot close to the origin for any illuminant ($a^* = b^* = 0$)

The L^*, C^*, h cylindrical coordinates are another set of color difference equations that are widely used and the equations are as follow:

- The cylindrical coordinates L^*, C^*, h

$$\begin{aligned} L^* &= 116(Y/Y_n)^{1/3} - 16 \\ C^* &= \left[(a^*)^2 + (b^*)^2\right]^{1/2} \\ h &= \arctan(b^*/a^*) \end{aligned} \qquad (2.2)$$

These values quantify the Munsell variables of hue, value and chroma, respectively. Value is quantified by L^* on a scale such as a perfect black has on L^* value of zero and the perfect reflection diffuser on L^* value of 100. Chroma is denoted by C^* and is measured on a scale such as a colorimetric neutral grey have C^* value of zero and fluorescent orange may have C^* value of 150. The hue angle is denoted in termed of h. Four psychological primary colors are as red, yellow, green and blue having approximate hue angle of 27°, 95°, 162° and 260°, respectively (*23*).

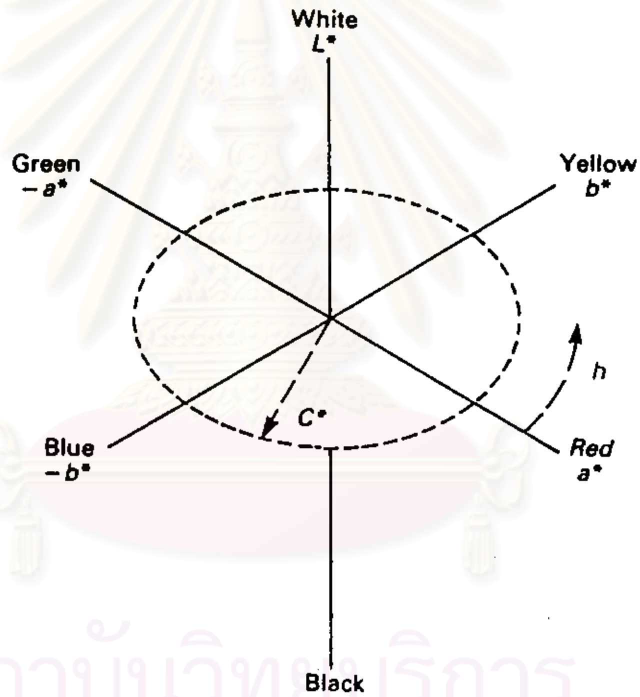

Figure 2-8 CIELAB color space

2.1.3 *The Simple Linear Regression*

Regression analysis (*24*) is a statistical technique for modeling and investigation the relationship between two or more variables. In general, suppose that there is a single dependent variable or response y that is related to k independent of regressor variables, $x_1, x_2, \ldots, x_k$. The response variable y is so called a random variable, while the regressor variables $x_1, x_2, \ldots, x_k$ are measured with negligible error. The regression model is fitted to a set of data. In some instances, the experimenter will know the exact form of the true functional relationship between y and $x_1, x_2, \ldots, x_k$. However, in most cases, the true functional relationship is unknown, the appropriate function to approximate the true function is carefully created. The simple model is the linear regression model, which is as follow

$$y = \beta_0 + \beta_1 x \tag{2.3}$$

where, β_0 = the intercept

β_1 = the slope

2.1.4 *The Correlation Coefficient*

The correlation coefficient (*25*), which is denoted by ρ, is a dimensionless quantity that measures the linear association between two random variables. The estimator of ρ is the sample correlation coefficient, r, that is following.

$$r = \frac{\sum_{i=1}^{n} y_i(x_i - \bar{x})}{\left[\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2\right]^{1/2}} \tag{2.4}$$

The sample correlation coefficient, r, measures the linear association between y and x, while β_1 measure the predicted change in the mean of y for a unit change in x. The meaning of r is following.

- The value of r will be on the interval [-1, +1].
- If r = 0 then y and x are not correlated.
- If the values of r are minus, the values of x are increase while the values of y are decrease and when the values of x are decrease, the values of y are increase.
- Conversely, if the values of r are plus, the values of x are increase, the values of y are increase and when the values of x are decrease, the values of y are also decrease.
- If the values of r near 1, x and y have high correlation in same direction.
- If the values of r near −1, x and y have high correlation but opposite direction.
- If the values of r near 0, the correlation between x and y are low.

2.2 Literature Review

The relation of the physical and the psychological parameters is important for color; however, a few research was conducted to bridge these two areas together. Some researchers put an attempt on investigating the instrumental assessment to explain this relationship.

Kobayashi (*26*) created a color image scale about the process and explained the system for classifying the color combinations. On this scale, the color was arranged according to three attributes: "Warm-Cool", "Soft-Hard" and "Clean-Grayish", which relate to the notation hue, value and chroma.

Nakamura et al. (*27*) analyzed quantitatively the "Cool-Warm" feeling of color in terms of colorimetric value which is supposed correlate with the affective tone of color. The results of visual experiment confirmed that the "Cool-Warm" feeling was affected by hue and brightness more than by hue and chroma. Therefore, the visual evaluation of the "Cool-Warm" feeling was compared with hue and brightness and calculated from the colorimetric values. The empirical formula represented the "Cool-Warm" was shown as follow.

$$CW = aBr-80 \tag{2.5}$$

where, Br : Brightness value

a : Coefficient , $a = 20\{\cos(\pi \times \Delta H_{5YR}/50) + 1\}$

ΔH_{5YR} : The Munsell hue step from 5YR

Sato et al. (*28*) presented the affective tone of color that was quantitatively analyzed from psychological view points. The fundamental factors were "Light-Dark", "Deep-Pale" and "Heavy-Light" feeling. The feeling of various color was verified with the above factors in terms of correlated colorimetric values which related to the affective tone. The visual assessment was compared with lightness, color depth and the other parameters which computed from the colorimetric values in order to set of empirical formulae. The affective tone of color indicated that the feeling is mainly affected by lightness and color depth.

Nakamura et al. (*29*) derived the color image formulae and expressed the visual assessment against twelve color image word pairs of "Vivid-Sombre", "Deep-Pale", "Warm-Cool", "Light-Dark", "Heavy-Light", "Gaudy-Plain", "Striking-Subdued", "Dynamic-Passive", "Distinct-Vague", "Transparent-Turbid", "Soft-Hard" and "Strong-Weak" to perform the numerical expression of the human color image perception. The visual assessment, which was compared with the Munsell and CIELAB values, was computed from the colorimetric values to establish the empirical formulae. Each value from the empirical formulae represented the color image value that made the color image diagrams and projected the Munsell and CIELAB color order system on those diagrams.

Sato et al. *(30)* performed a visual experiment to analyze quantitatively the feelings of color in terms of colorimetric values. The visual experiment confirmed that the feelings were mainly affected by Munsell chroma and Munsell value. Finally, the empirical formulae were established to represent the feeling as follow.

$$CI = [\{k_v(V-V_0)\}^2 + \{k_c(C-C_0\}^2]^{1/2} - k_s \tag{2.6}$$

where, CI : Color image value

V : Munsell value

C : Munsell chroma

V_0 : Munsell value when the color image percent is minimum

C_0 : Munsell chroma when the color image percent is minimum

k_v : Constant of the contribution of Munsell value for the color image

k_c : Constant of the contribution of Munsell chroma for the color image

k_s : Constant for the scaling of the color image

Ho *(31)* studied about the relationship between colorimetric values and each opponent pair of the color images, "Warm-Cool", "Dynamic-Passive", "Light-Dark" and "Soft-Hard". The model formulae of each opponent pair of the color image was derived and the difference of the color images between the Japanese and

British observers were also examined. Hue and chroma influenced "Warm-Cool" color image. "Dynamic-Passive" color image was dominated by chroma. "Light-Dark" color image was directly proportional to the lightness. Lightness and chroma determined "Soft-Hard" color image. The difference between the British observers in "Soft-Hard" color image was found that Chroma C* more than 65 gave the British observers a "Hard" image while the same color gave the Japanese observers a "Soft" image. The "Light-Dark" color image for British observers had a higher correlation with the lightness than Japanese observers.

Ohmi et al. (*32*) studied the effect of color from two point of view. First, the relation between structure of fundamental emotion and affective meaning of color; and secondly, the effect of culture difference on meanings of color. This work examined the generality and heterogeneity of meanings of color among Japanese, Korean and American. The structure of meanings of color has a high level of generality beyond cultural differences. Color is considered to communicate more social and more cultural meaning as well as biological or physiological perception. Regarding, the comparison of color associated with individual emotions, a high resemblance was found between Japan and Korea, and there was some heterogeneity between these two nations and the United States of America. This was caused by cultural resemblance and geographical distance.

Sato et al. (*33*) used the numerical expression of color emotion to find the instrumentally assessment. The twenty-four color emotion formulae based on the Munsell and CIELAB 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.