CHAPTER 5

RESULTS AND DISCUSSION

5.1 The GOG model and Analysis of efficacy

In the actual monitor, tone reproduction characteristics are not represented with the inherent gamma coefficient of the display system. And the brightness and contrast very, γ is changed, as well as offset and gain. The change in γ would bring nonlinearity to the relationship between DAC count and brightness level. This problem must be considered previously before selecting brightness and contrast levels. The optimum brightness level has to get the least luminance of black as soon as possible. And the optimum contrast level is the level, which obtain the constant gamma coefficient.

Normally, the difference of gamma decreases as the level of contrast increases. Therefore, the selecting of contrast level has not to obtain the low level. And the optimum monitor setup has to consider the optimum brightness level before the optimum contrast level.

According to the experimental setup, the LUT (Look-up table) data of CRT monitor are created from the measuring of spectrophotometer.

These LUT data is the data into the Input data for the calculation of Monitor profile and GOG (gain-offset-gamma) model. And it is measured in x, y, and L values as shown in Table 5-1.

These values are calculated into XYZ tristimulus (X = x.L/y, Y = L, and Z = z.L/y) [5]

Table 5-1 Input data for Monitor profile creation

Digital count			x	y	z	L
R	G	B				
255	0	0	0.6478	0.3383	0.0139	18.2
0	255	0	0.2904	0.6074	0.1022	49.7
0	0	255	0.1488	0.0623	0.789	5.78
0	0	0	0.3462	0.3543	0.2995	0.262
16	16	16	0.3469	0.3538	0.2993	0.273
32	32	32	0.3485	0.3498	0.3017	0.391
48	48	48	0.343	0.348	0.309	0.784
64	64	64	0.334	0.3476	0.3184	1.70
80	80	80	0.3265	0.3421	0.3314	3.26
96	96	96	0.3228	0.3395	0.3377	5.29
112	112	112	0.3196	0.3375	0.3429	8.15
128	128	128	0.3176	0.3356	0.3468	11.6
144	144	144	0.3161	0.3347	0.3492	16.2
160	160	160	0.3152	0.3334	0.3514	21.3
176	176	176	0.3144	0.3332	0.3524	28.2
192	192	192	0.314	0.3319	0.3541	35.8
208	208	208	0.3142	0.3334	0.3524	42.9
224	224	224	0.3139	0.3318	0.3543	52.5
240	240	240	0.3118	0.3297	0.3585	62.1
255	255	255	0.313	0.3302	0.3568	73.5

The obtained tristimulus value of each channel are used to calculate the scalar values where R = X/Xmax, G = Y/Ymax, and B = Z/Zmax. These data are shown in the Table 5-2.

Table 5-2 The data between the DAC counts and Scalar.

Digital count	X_r	Y_g	Z_b	**Scalar**		
				R	**G**	**B**
0	0.128	0.177	0.204	0.0037	0.0036	0.0028
16	0.134	0.185	0.213	0.0038	0.0037	0.0029
32	0.195	0.264	0.311	0.0056	0.0053	0.0042
48	0.387	0.53	0.642	0.011	0.011	0.0088
64	0.817	1.15	1.435	0.0234	0.023	0.02
80	1.556	2.204	2.91	0.0447	0.044	0.04
96	2.516	3.577	4.849	0.072	0.072	0.066
112	3.861	5.511	7.631	0.111	0.111	0.104
128	5.491	7.844	11.047	0.158	0.158	0.151
144	7.653	10.954	15.576	0.22	0.22	0.213
160	10.073	14.403	20.689	0.29	0.29	0.283
176	13.31	19.07	27.49	0.382	0.384	0.376
192	16.942	24.208	35.20	0.486	0.487	0.481
208	20.223	29.01	41.79	0.58	0.584	0.571
224	24.84	35.5	51.663	0.713	0.714	0.706
240	29.38	41.99	62.23	0.843	0.845	0.85
255	34.851	49.7	73.192	1.0	1.0	1.0

All three channels have the nonlinear relationship between the digital counts and Scalar R, G, and B as following in Figure 5-1, 5-2, and 5-3.

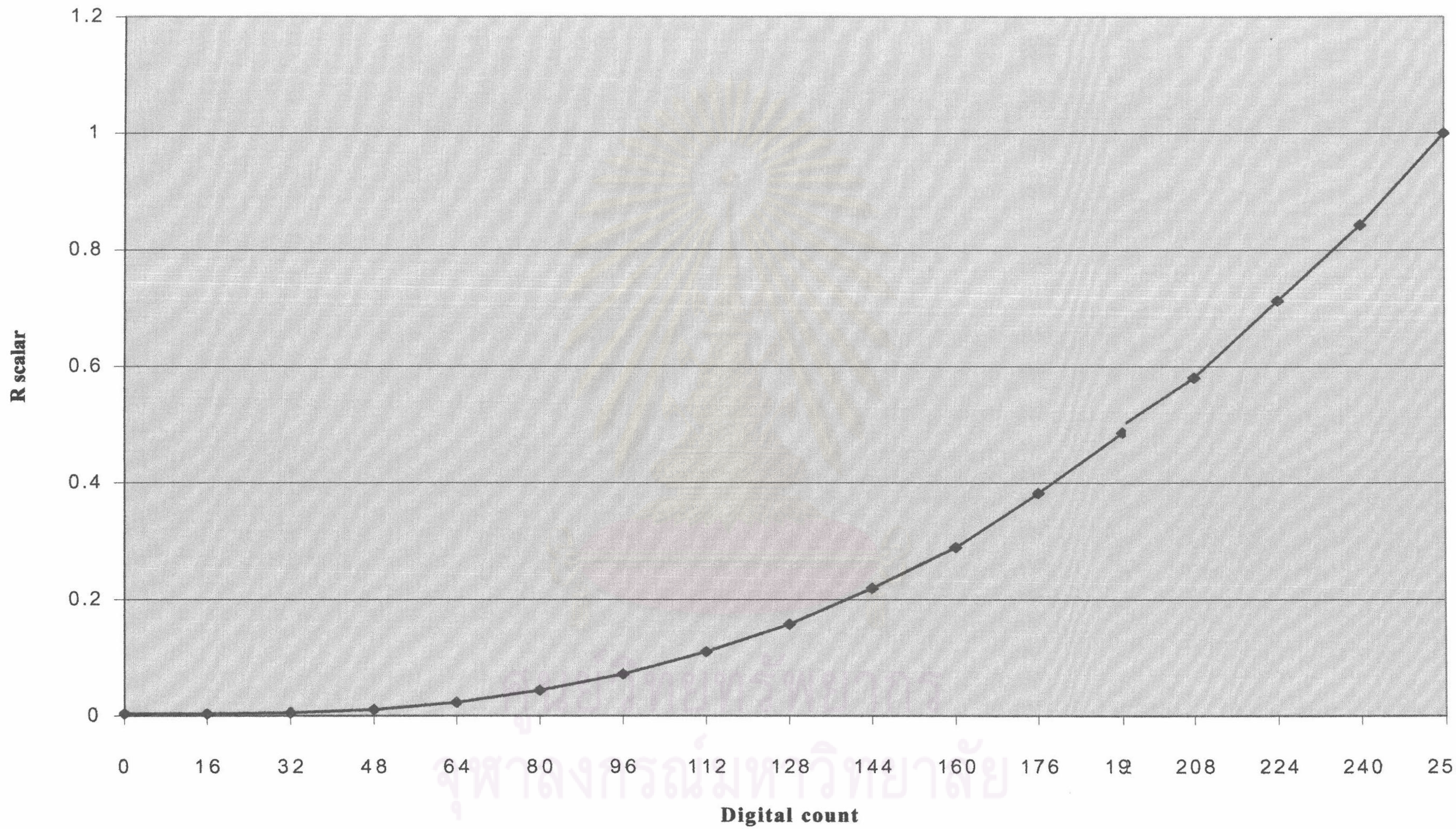

Figure 5-1 The relationship between Digital count and R scalar

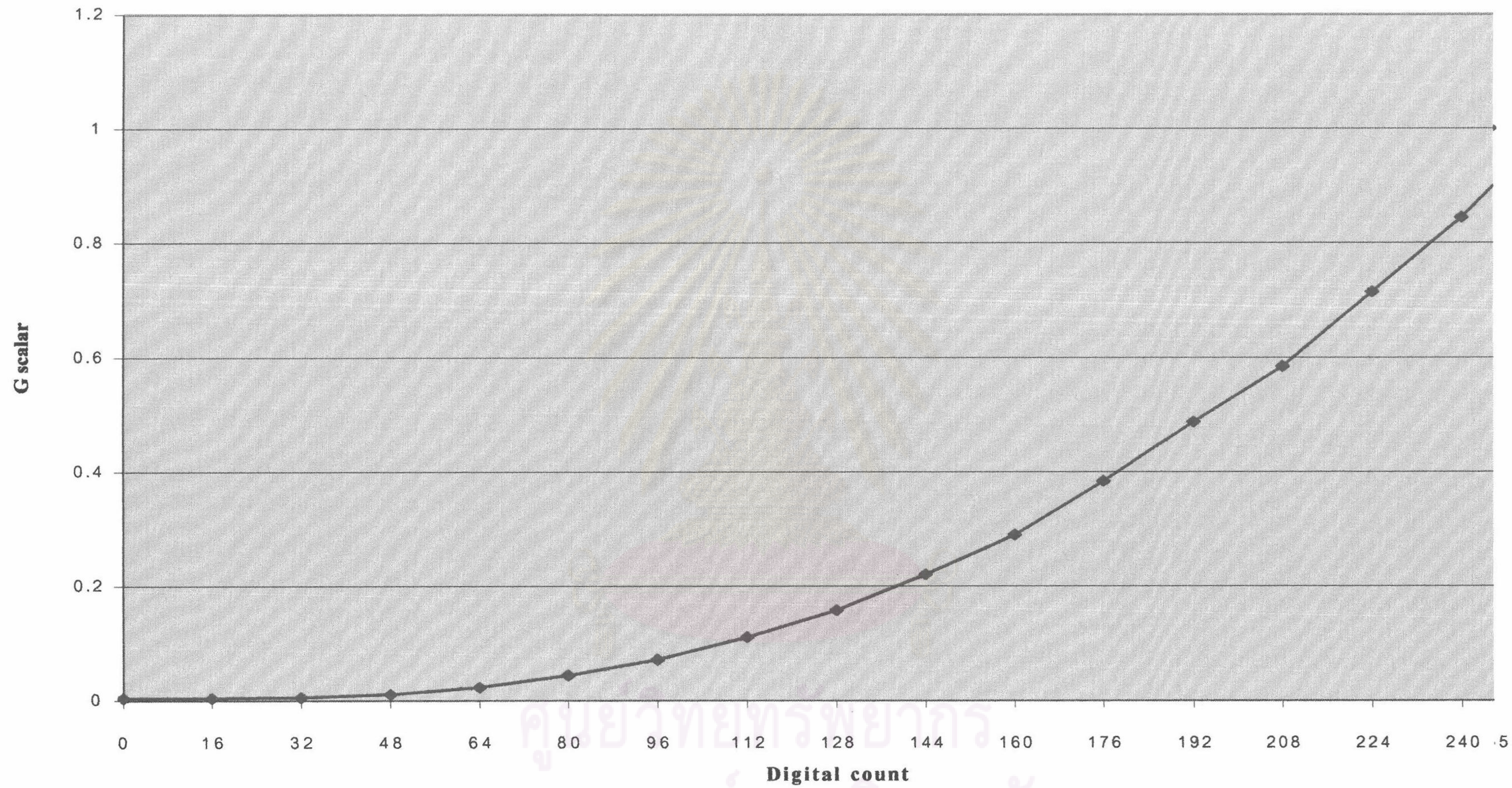

Figure 5-2 The relationship between Digital count and G scalar

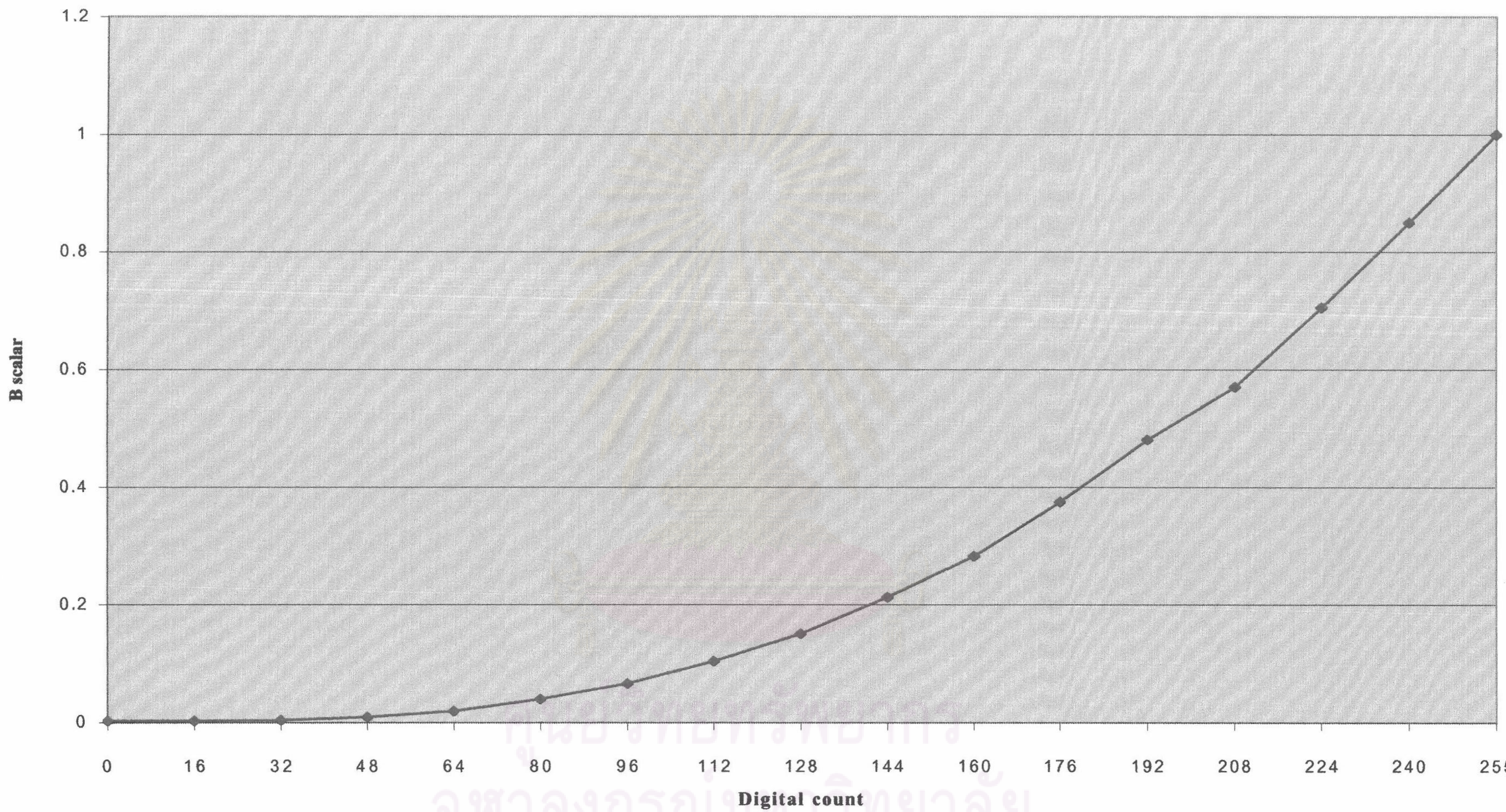

Figure 5-3 The relationship between Digital count and B scalar

Because the scalar values are normalized by dividing their respective maximum values. These normalized values are used to estimate parameters for the nonlinear transform from DAC values to monitor RGB values using the following Eq.(5.1)

$$R/R\,max = \left\{ k_{g,r} \; (d_r/255) + \; k_{o,r} \right\}^{\gamma_r}, R/R\,max > 0 \tag{5.1}$$

Further approximation can be made to Eq. (5.1) by setting the following relationship:

$$k'_{g,r}\left(d_r/255\right) = k_{g,r}\left(d_r/255\right) + k_{o,r} \tag{5.2}$$

Substituting this approximation in Eq. (5.1), we obtain

$$R/R\,max = \left\{ k'_{g,r} \; (d_r/255) \right\}^{\gamma_r}$$

or

$$\log\left(R/R\,max\right) = \gamma_r \log\left(d_r/d_{max}\right) + \gamma_r \log k'_{g,r} \tag{5.3}$$

The validity of this approximation can be verified by plotting log (R/Rmax) vs. log (d_r/d_{max}). If a linear relationship exists, the approximation is good and the slope is gamma. The intercept divided by gamma is log $k'_{g,r}$. Figure 5-4, 5-5, and 5-6 is the logarithmic plot of RGB levels in Table 5-2; very good linear relationships are obtained.

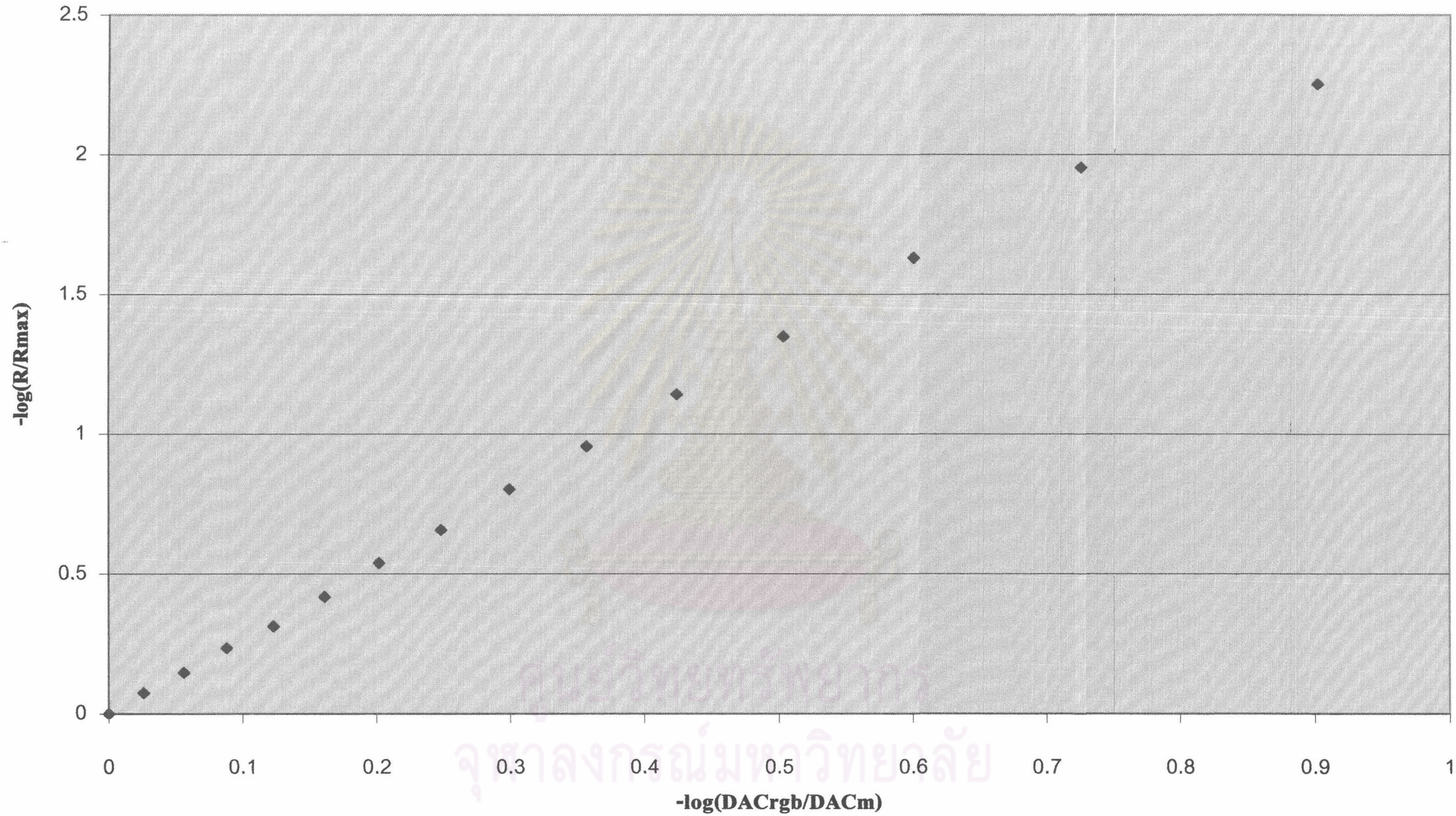

Figure 5-4 The logarithmic plot of R level.

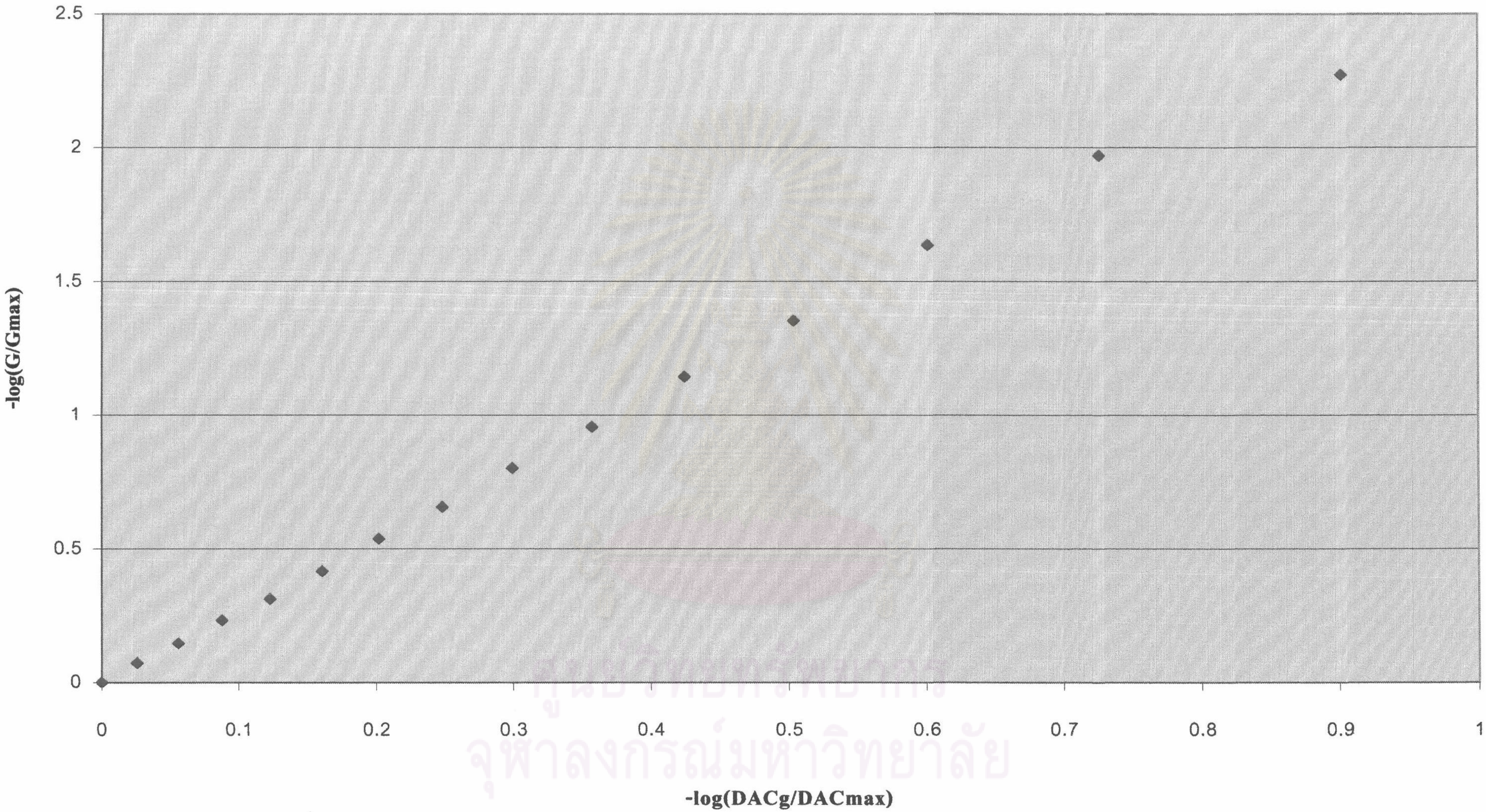

Figure 5-5 The logarithmic plot of G level

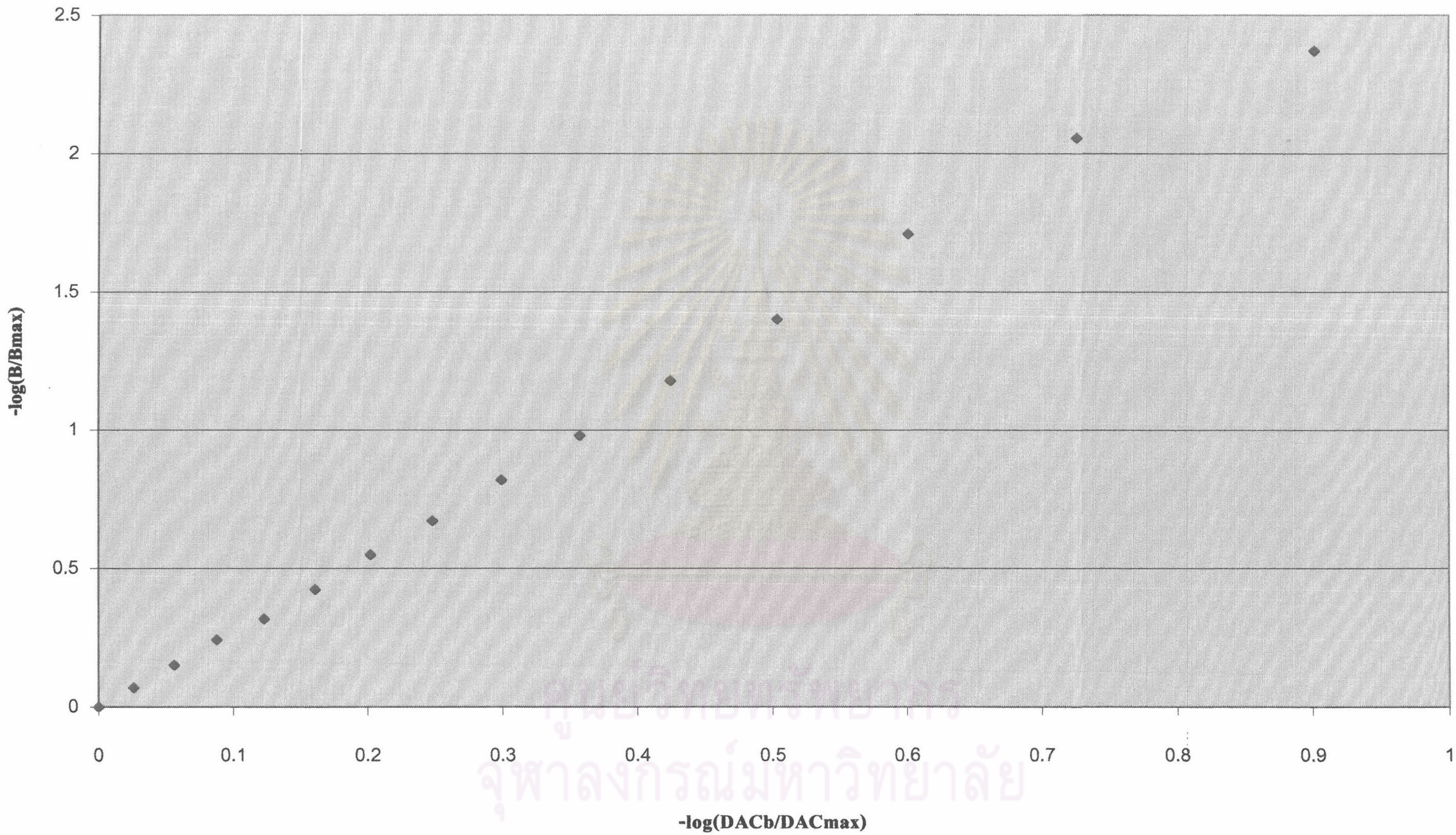

Figure 5-6 The logarithmic plot of B level

Table 5-3 The data of Gamma, Offset, and Gain

Channel	Gamma	Offset	Gain
R	2.518	-0.040	1.040
G	2.375	-0.085	1.085
B	2.456	-0.081	1.081

Therefore, we obtained the GOG model as following in Eq. 5.4, 5.5, and 5.6.

$$R = \left[1.04 \left(\frac{d_r}{255} \right) - 0.04 \right]^{2.518} \quad (5.4)$$

$$G = \left[1.09 \left(\frac{d_g}{255} \right) - 0.09 \right]^{2.375} \quad (5.5)$$

$$B = \left[1.08 \left(\frac{d_b}{255} \right) - 0.08 \right]^{2.456} \quad (5.6)$$

And inverse GOG model as following in Eq. (5.7), (5.8), and (5.9):

$$d_r = \left[R^{1/2.518} + 0.04 \right] \left[\frac{255}{1.04} \right] \quad (5.7)$$

$$d_b = \left[B^{1/2.456} + 0.081 \right] \left[\frac{255}{1.081} \right] \quad (5.8)$$

$$d_g = \left[G^{1/2.375} + 0.085\right]\left[\frac{255}{1.085}\right] \quad (5.9)$$

The GOG model can be examined the efficacy by measurement the standard deviation and average of the ΔR, ΔG, and ΔB, which are difference of the scalar value of RGB levels in three channels between the measured values on the monitor and the values, which calculated from GOG model.

Table 5-4 The ΔR, ΔG, and ΔB of red, green, and blue channel.

Digital count	ΔR	ΔG	ΔB
0	-	-	-
16	0.0037	-	-
32	0.0032	0.0045	0.0035
48	0.0019	0.0043	0.003
64	0.0011	0.0044	0.0026
80	0.0018	0.0052	0.0038
96	0.0004	0.0034	0.0025
112	0.0005	0.003	0.0029
128	0.0016	0	0.0011
144	0.0005	0.0013	0.003
160	0.0019	0.0026	0.0006
176	0.0064	0.0057	0.0082
192	0.0128	0.0105	0.0147
208	0.0048	0.005	0.0085
224	0.0014	0.0004	0.0016
240	0.01	0.01	0.0008
255	0	0	0

The standard deviation and the average of ΔR, ΔG, and ΔB as shown in Table 5-5.

Table 5-5 The Average and the standard deviation of ΔR, ΔG, and ΔB channels.

Differences	**Average**	**Standard deviation**
ΔR	0.0033	0.0035
ΔG	0.0045	0.0031
ΔB	0.0038	0.0037

The results in Table 5-5 have the average of the difference less than 0.05 and the standard deviations are very low. Thus, this GOG model is an acceptable model.

5.2 The Transformation matrix and analysis of efficacy

We described earlier in Chapter 2 how the principles of additive color mixing apply to computer controlled CRT displays. Thus, the relationship between display primaries and tristimulus values is linear, expressed by Eq. (5.10):

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} X_{r,max} & X_{g,max} & X_{b,max} \\ Y_{r,max} & Y_{g,max} & Y_{b,max} \\ Z_{r,max} & Z_{g,max} & Z_{b,max} \end{bmatrix} \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix} \qquad (5.10)$$

When a color system is described by Eq. (5.10), it 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 a chromaticity matrix and a luminance matrix, shown in Eq. (5.11):

$$\begin{bmatrix} X_{r,max} & X_{g,max} & X_{b,max} \\ Y_{r,max} & Y_{g,max} & Y_{b,max} \\ Z_{r,max} & Z_{g,max} & Z_{b,max} \end{bmatrix} = \begin{bmatrix} (x_{r,max}/y_{r,max}) & (x_{g,max}/y_{g,max}) & (x_{b,max}/y_{b,max}) \\ 1 & 1 & 1 \\ (z_{r,max}/y_{r,max}) & (z_{g,max}/y_{g,max}) & (z_{b,max}/y_{b,max}) \end{bmatrix} \begin{bmatrix} L_{r,max} & 0 & 0 \\ 0 & L_{g,max} & 0 \\ 0 & 0 & L_{b,max} \end{bmatrix} \quad (5.11)$$

where x_r, x_g, …, z_g, z_b are chromaticities of each primary in LUT data, which measured by spectrophotometer. And $L_{r,max}$, $L_{g,max}$, and $L_{b,max}$ are maximum luminance in LUT data, which measured by spectrophotometer.

Therefore, in this research, we obtained the primary tristimulus or the transformation matrix as shown in Eq. (5.12):

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 34.851 & 23.762 & 13.805 \\ 18.2 & 49.7 & 5.78 \\ 0.748 & 8.362 & 73.192 \end{bmatrix} \cdot \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (5.12)$$

And Inverse transformation matrix as shown in Eq. (5.13):

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 0.038 & -0.017 & -0.0058 \\ -0.014 & 0.0267 & 0.00052 \\ 0.0012 & -0.0029 & 0.01366 \end{bmatrix} \cdot \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \qquad (5.13)$$

In order to demonstrate the efficacy of the monitor profile, the 47 color samples was tested by the randomness of the DAC counts for the individual channel. With the determined gamma coefficients and a single transformation matrix based on the maximum red, green, and blue, the tristimulus values of the 44 test color samples can be predicted. All the same, with the determined sRGB system's profile, the tristimulus values of 44 test color samples can be predicted too. CIELAB color differences (ΔE^*_{ab}) were calculated between measurements by spectrophotometer and both predictions, where the monitor peak white was used to define X_n, Y_n, and Z_n in the CIELAB equations.

The efficacy of monitor profile can be examined by the standard deviation and the average of the difference of color, which are calculated into the CIELAB color difference (ΔE^*_{ab}).

In this research, we compared the results of ΔE^*_{ab} between transfomation by the obtained monitor profile and the sRGB system's profile as shown in Table 5-6.

Table 5-6 The average and standard deviation of ΔE^*_{ab} between the transformation through monitor profile and the sRGB's profile.

Types of profile	ΔE^*_{ab}	
	Average	**S.D.**
Monitor profile	0.55	0.21
sRGB's profile	4.98	2.11

Figure 5-7, 5-8, and 5-9 show the distribution of color differences as a function of L* of the 45 test colors for the monitor profile, sRGB's profile, and both of the monitor profile and sRGB's profile.

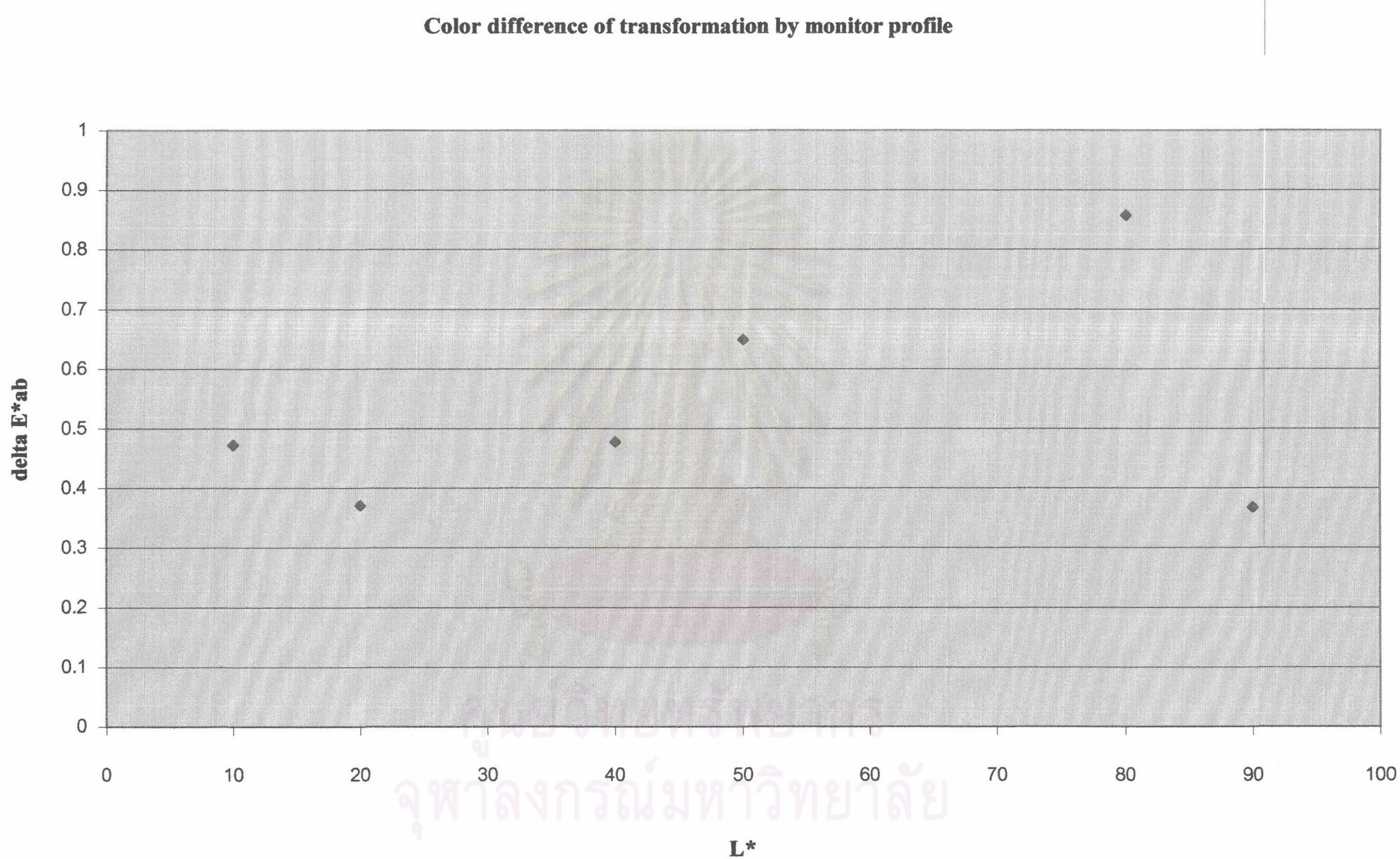

Figure 5-7 The color differences of the monitor profile

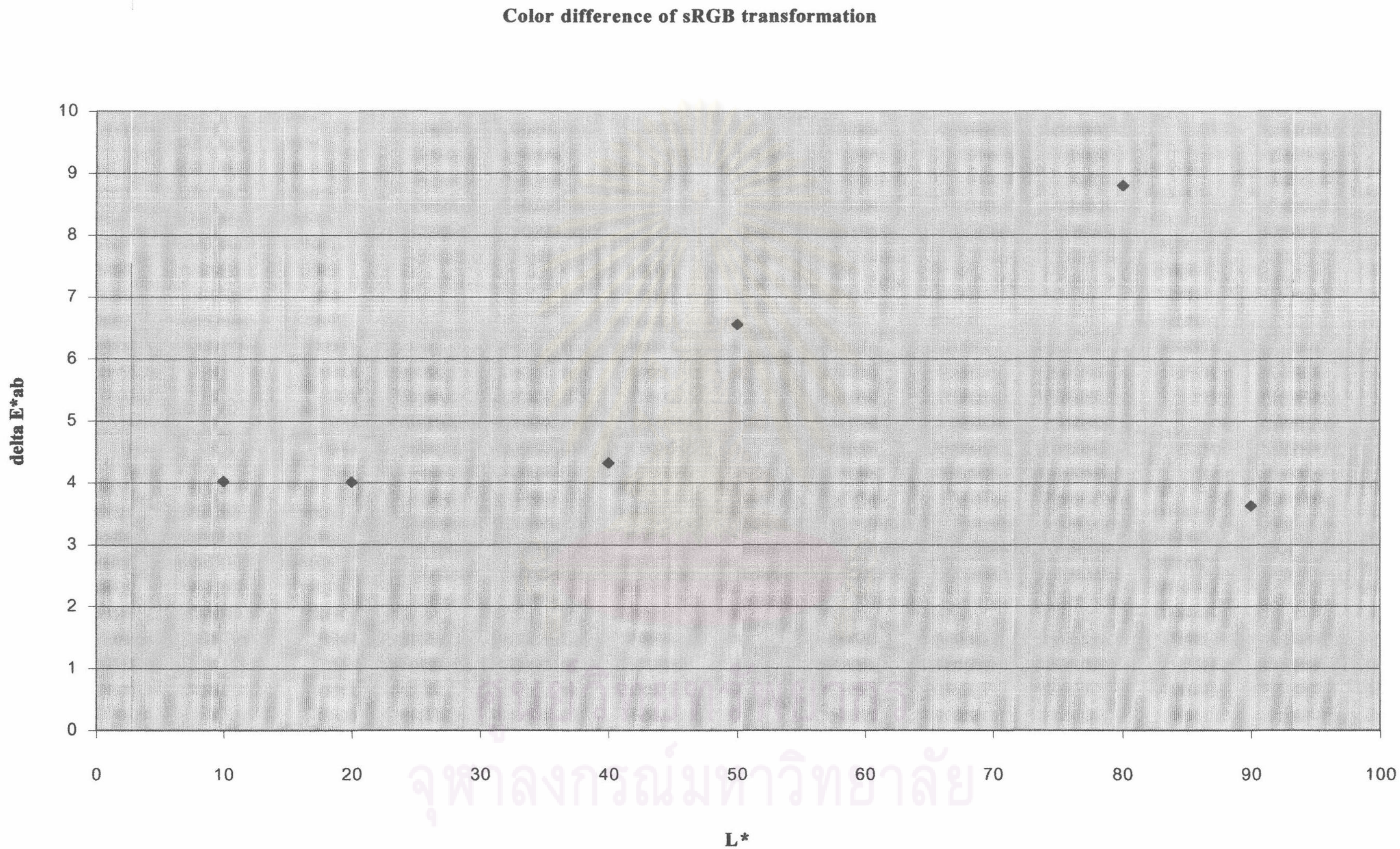

Figure 5-8 The color differences of sRGB's profile

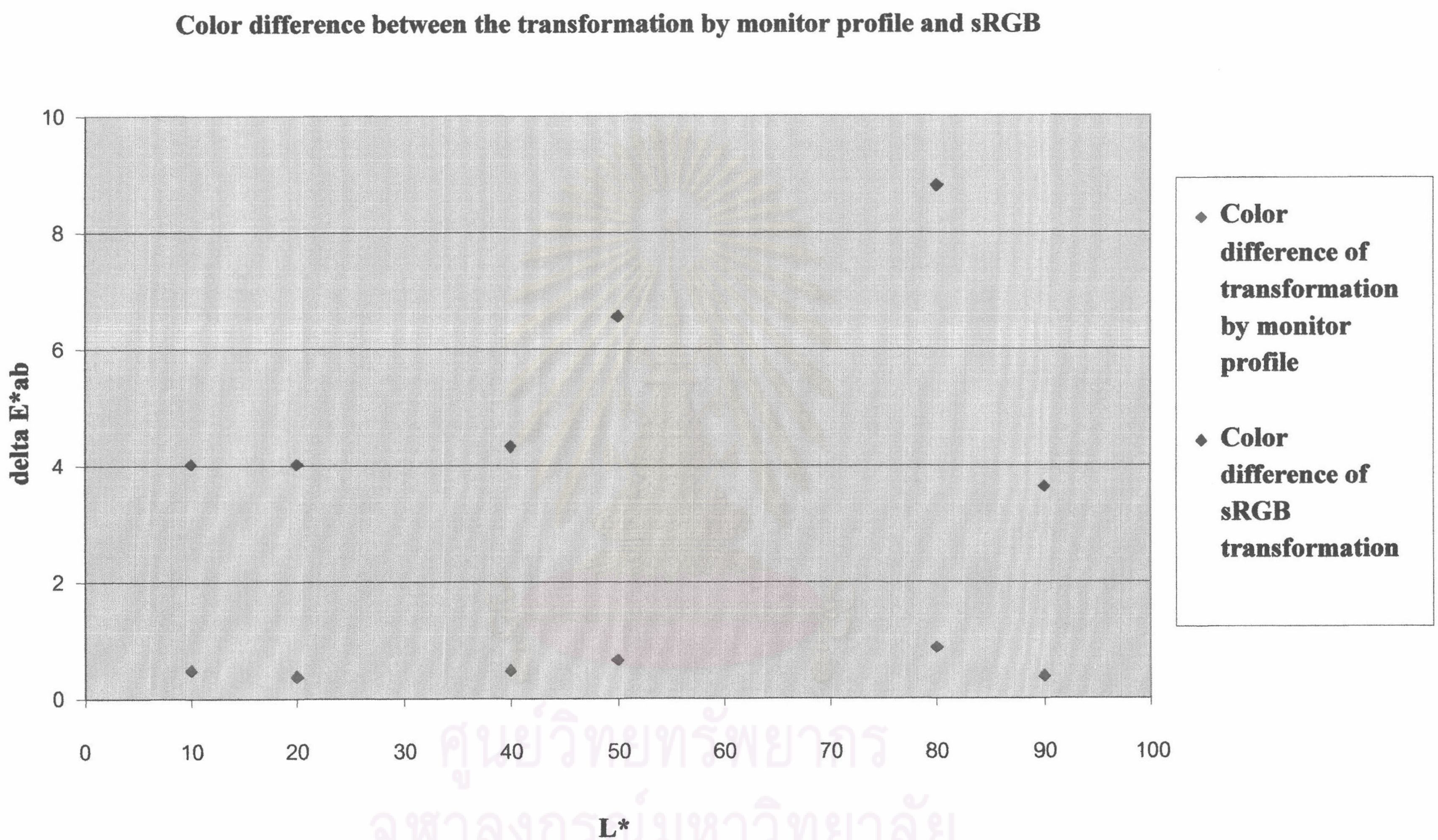

Figure 5-9 The color differences between both of the profile

The results from Table 5-6 show that the average and S.D. of difference of the CIELAB color difference of the monitor profile is very low and less than 2.0. Thus, this monitor profile is a acceptable profile. And the transformation of colors through the monitor profile receives smaller color differences than the transformation of colors through sRGB system's profile. Therefore, the monitor profile is a more suitable tool for the experimental monitor.

But, for the color communication on the Internet, the difference system of monitor has created the burden of CMS because each monitor system has not the same monitor profile. Therefore, to avoid this problem, the sRGB's profile is created. And sRGB's profile is a more suitable tool for the color communication on the Internet.