Color Conversion from RGB to RGB+White While Preserving Hue and Saturation

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Abstract

In this paper, the method to increase the display intensity while preserving the hue and saturation of the input color is proposed in RGB+White 4-channel display devices. For this approach, the color gamut of the RGBW display is analyzed. The input color vector, incremental vector for increasing intensity, and a value for the white channel are analyzed and processed together in the color vector space. By this analysis, the proper correction vector for increasing the intensity and preserving the saturation can be obtained easily. The image test for this algorithm gives a good result for the brightness and saturation so that one can find out brighter image with vivid color without color clipping.

Introduction

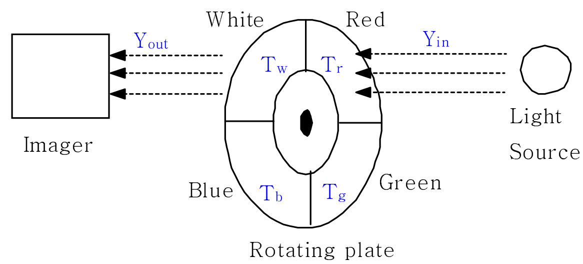
There are many color display devices such as micro-displays(LCoS : Liquid Crystal on Silicon, DMD: Digital Micro-mirror Device), and PDP (plasma display panel) widely used these days for TV and computer monitors. The market of these display devices gets growing quickly over the existing CRT market. In order to surpass the output light intensity of the CRT, high-powered lamps or electrodes are generally utilized in LCoS, DMD, and PDP. Recently, there have been many research works reported to increase the light intensity of the display devices by employing an efficient optical system[1,2] or by adding a white channel[3~6] as well as by improving chemical and material substances.

A method proposed by Kunzman and Pettitt[3] increases brightness of display devices by adding a white channel preserving a high rate of light transmission to red, green, and blue filter. This allows a substantial increment in light quantity per frame emitting on DMD. However, the intensity increment by using the white filter causes a degradation of the image quality by lowering its color saturation. The size of the white filter segment is lessened in order to remedy this problem while this solution again lowers the amount of the intensity increment.

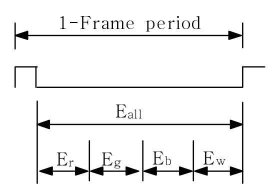
The main purpose of this paper is to propose and verify a method that can increase the light intensity to the utmost and keep the original image quality at the same time.

RGB+White 4-Color Display

Figure 1 demonstrates a 1 panel projection display composed of 4 color filters (i.e. red, green, blue, and white).



(a)



(b)

Figure 1. Example of the Single panel Display (a) Engine Architecture (b) Timing chart

Assume that the input light intensity is Y_{in}, the transmittances of RGB and white filter are T_r, T_g, T_b, T_w, and the expose times per frame of R,G,B,W are E_r, E_g, E_b, E_w, the output light intensity, Y_{out}, can be obtained as follows:

$$Y_{out} = Y_{in} * (T_r * E_r + T_g * E_g + T_b * E_b + T_w * E_w) \quad (1)$$

For instance, assume that the intensity of back-light is 100, and the transmittance of RGB filters are 1/3 while the transmittance of white filter is 1. When the light expose time for each R,G,B filter is 1/3, the light intensity emitted from this display device would be around 33.33. If we employ RGBW 4-color filter instead of RGB 3-color filter and set the exposed time to 1/4 for each filter (i.e. E_r=E_g=E_b=E_w = 1/4), the light intensity would increase to

50. This results in approximately 50% brightness improvement of the display device. Fig. 2 plots the changes of the light intensity according to the changes in the expose time of white channel. They show the linearity and the output light intensity can be up to 66.67 when the exposed time ratio of the white channel becomes 0.5.

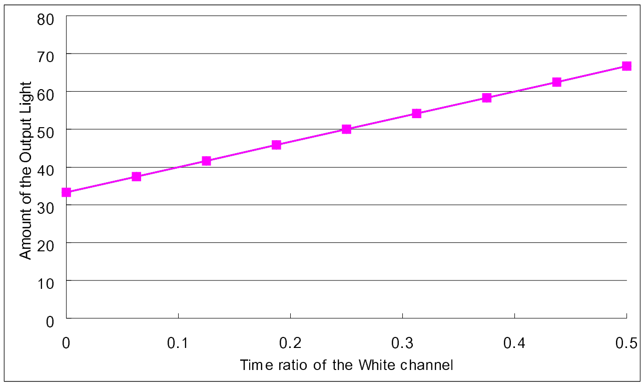


Figure 2. Time ratio of White channel vs. Output light intensity

This feature determines the size of the white filter on behalf of the target output light intensity.

RGBW Processing for Preserving Hue and Chroma

This section introduces the mechanism of 4-color processing that increases the brightness and keeps the hue and chroma at the same time.

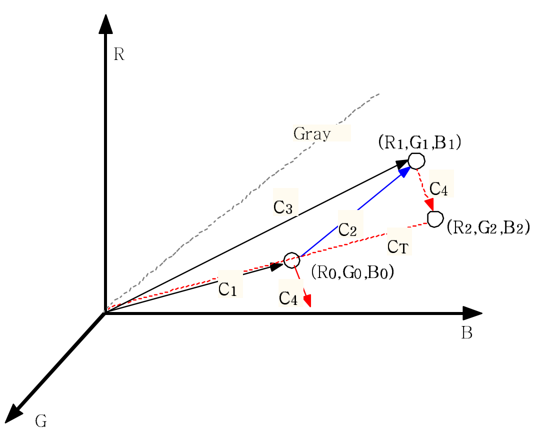


Figure 3. Vector representation of Color addition

Suppose there are 2 color signals $\mathbf{C_1}$ and $\mathbf{C_2}$. The summation of two color signals can be represented by an inner product of two vectors as follows

$$C_3(m_3, v_3) = C_1(m_1, v_1) \bullet C_2(m_2, v_2) \qquad (2)$$

where "m" is a magnitude of the signal, "v" is the direction of the vector of each signal, the symbol **"•"** is an inner product, and $\mathbf{C_i}$ (i=1,2,3) represents the color signals.

Figure 3 demonstrates the color $\mathbf{C_3}$, which is a mixture of the input color $\mathbf{C_1}$ and the white color $\mathbf{C_2}$ increasing the light intensity. Note that the color $\mathbf{C_3}$ has a different direction from the input color $\mathbf{C_1}$. Although this increases the light intensity, the result color looks different from the color of the input image. Therefore, we need a compensation process to preserve the color $\mathbf{C_1}$. In order to coincide the direction of $\mathbf{C_1}$ and $\mathbf{C_3}$, we calculate the color $\mathbf{C_T}$ from an inner product of $\mathbf{C_2}$ and $\mathbf{C_4}$ as follows:

$$C_T(m_T, v_T) = C_1(m_1, v_1) \bullet \{C_2(m_2, v_2) \bullet C_4(m_4, v_4)\} \quad (3)$$

The magnitude m_4 and directional vector v_4 of compensation vector $\mathbf{C_4}$ is a function of m_1, v_1, m_2, and v_2. Equation (3) is not a sufficient condition to reproduce natural colors of the input color. We should consider the amount of the white signal applied as well as the whole gamut of the RGBW color space.

4-color space is not a cube as in RGB color space. Fig. 4 is an illustration of 2D gamut using the RG and White channel. The input RG color space covers the square [Org-R'-F-G'] while the RGW color space gamut covers the polygonal region [Org-G'-A-D-B-R']. The two triangle regions, [G'-G"-A] and [B-R'-R"] are the regions incapable of describing any color.

The size of W-gamut(region [A-D-B-F]), W_{scale}, is determined by the ratio of light intensities emitted between white channel and RGB channels.

$$W_{scale} = \frac{T_w * E_w}{T_r * E_r + T_g * E_g + T_b * E_b} \qquad (4)$$

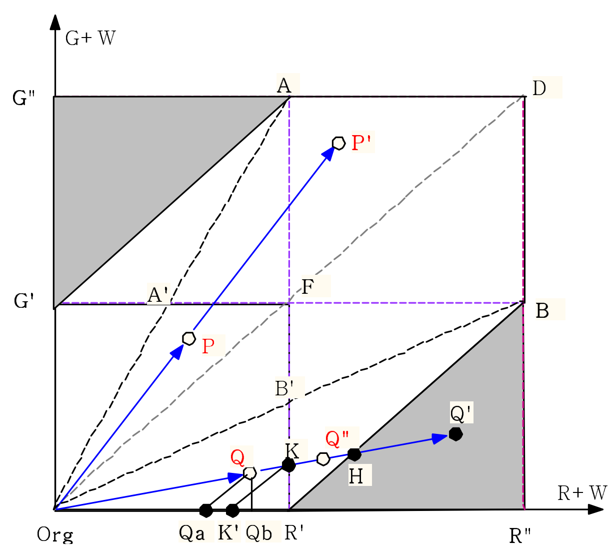


Figure 4. Color Gamut of RGBW Display (2D plot)

As shown in the Fig. 4, the colors inside the region [Org-A'-F-B'] can increase their magnitudes while maintaining the vector direction. However, the colors outside the region [Org-A'-F-B'](i.e. [Org-G'-A'] and [Org-R'-B']) can be projected to the space that is incapable of describing any color (i.e. [G'-G"-A] and [B-R'-R"]).

Therefore, we have to process the colors in the area [Org-A'-F-B'](i.e. Constant Scaling Space) separately from the colors in the region[Org-G'-A'] and [Org-R'-B'](i.e. Gamut Scaling Space). We should also derive the new scale value for the colors located in the two triangles [Org-G'-A'] and [Org-R'-B'] with respect to the coordinate of the entire gamut hull.

Algorithm

The transformation process from RGB color space to RGBW color space consists of 3 major steps.

1) Judging the kind of the color space that the input color belongs to (i.e. CSS or GSS)
2) Scaling of the input color
3) Segregating White signal and RGB signals from the scaled signal obtained.

Determination of Scale Space

Assume that there is a input color R_0,G_0,B_0 (point **P** or **Q** in Fig. 4). Whether the input color is in the quadrangle region [Org-A'-F-B'](i.e. CSS) or in the triangle regions [Org-G'-A'], [Org-R'-B'](i.e. GSS) can be determined by a process as follows:

$$\begin{array}{ll} IF\ M_1 > M_2 * (1+W_{scale}), & input\ color \subset GSS \\ ELSE & input\ color \subset CSS \end{array} \quad (5)$$

Where, M_1 = maximum(R_0,G_0,B_0)
M_2 = minimum(R_0,G_0,B_0)

Scaling Input Signal

In the second step, if input signal is in the CSS(Constant Scaling Space), the scaled signal can be obtained simply by multiplying a predetermined scale constant, S_2 , to each RGB channel.

$$S_2 = 1 + W_{scale} \quad (6)$$

The scaled signal, R_2,G_2,B_2 can be obtained simply by multiplying a scale constant, S_2 , to each RGB channel.

$$R_2 = S_2 * R_o,\ G_2 = S_2 * G_o,\ B_2 = S_2 * B_o \quad (7)$$

For example, if the input color is point **P**, the scaled color would be a point **P'** by equation (6) as shown in Fig. 4.

A color signal process in GSS(Gamut Scaling Space), which depends upon the gamut coordination, is as follows. A scaling value, S_1, can be calculated from $|IP_1|$ and $|IP_2|$. The IP_1 is an intersection point of the extended input color vector and the RGB color gamut hull. IP_2 is an intersection point of the extended input color vector and the RGBW color gamut hull. The symbol "|x|" means the distance from point Org to point x. of For example, the IP_1 and IP_2 are equivalent to the **|K|** and **|H|** in Fig. 4. Since it is complex to calculate point **|H|** directly, we can simplify the calculation of scaling ratio S_1 in the following manner. Since the line [R'-B] is parallel to the line [K-K'], the ratio of **|H|** and **|K|** is equivalent to the ratio of **|R'|** and **|K'|**. For any arbitrary color **Q** on the same color vector, the same ratio can be obtained by using $|\mathbf{Q_b}|$ and $|\mathbf{Q_a}|$. Again line [**R'-B**] is parallel to line [**Q-Qa**].

$$S_1 = \frac{|IP_1|}{|IP_2|} = \frac{|H|}{|K|} = \frac{|R'|}{|K'|} = \frac{|Q_b|}{|Q_a|} \quad (8)$$

Where, the point $\mathbf{Q_b}$ can be calculated by the maximum value of a input RGB and the point $\mathbf{Q_a}$ also obtains by the difference between maximum value and weighted minimum one.

$$S_1 = \frac{M_1}{M_1 - (W_{scale} * M_2)} \quad (9)$$

The scaled signal, R_2,G_2,B_2 can be obtained simply by replacing S_2 of equation(7) by S_1 of equation(9).

Separation to RGB and White Signal

The process for extracting the output signal of white channel from the scaled one is too simple.

$$W_{out} = \text{minimum}(R_2, G_2, B_2) \quad (10)$$

The RGB channel outputs R_{out}, G_{out}, B_{out} can be calculated by subtracting W_{out} from R_2, G_2, B_2

$$\begin{aligned} R_{out} &= R_2 - W_{out} \\ G_{out} &= G_2 - W_{out} \\ B_{out} &= B_2 - W_{out} \end{aligned} \quad (11)$$

Finally let us consider the color value of white filter and RGB filter. Assume that RGB combined XYZ values are X_{cw},Y_{cw},Z_{cw} and White filter's XYZ values are X_w,Y_w, Z_w. These values of two sets are mostly different. So we need to correct either white signal or RGB signal during separating the scaled signal into RGBW signal. When we assume that the R_a,G_a,B_a are the ratio between the maximum RGB value of the summation of RGB filters and the maximum RGB value of the white filter, the equation(11) can be rearranged as follows:

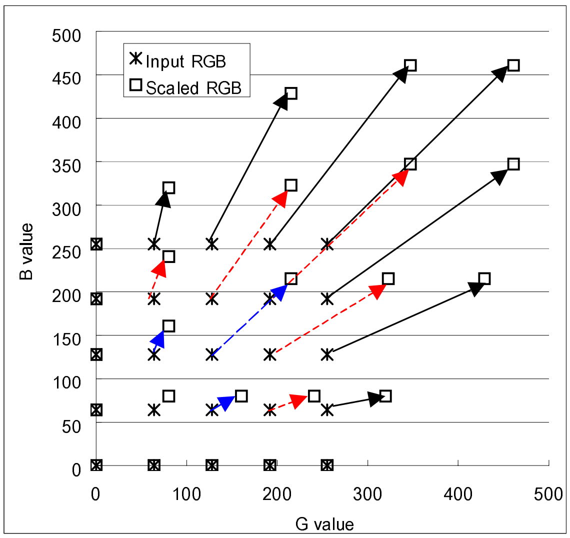
$$\begin{aligned} R_{out} &= R_2 - W_{out} * R_a \\ G_{out} &= G_2 - W_{out} * G_a \\ B_{out} &= B_2 - W_{out} * B_a \end{aligned} \quad (12)$$

Now the output signals R_{out},G_{out},B_{out} are corrected to remedy the mismatch between RGB combined color and White filter's.

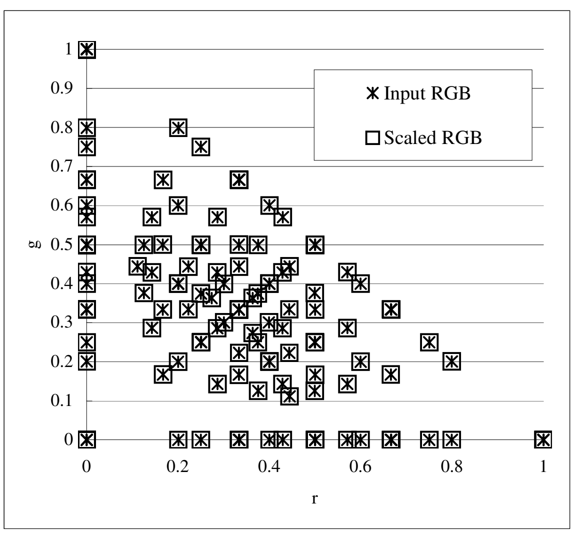
Experimental Results

Test for Mapping Relation Between Input and Scaled Color

This section describes the results of signal mapping relation between input RGB(= R_0,G_0,B_0) and scaled RGB(= R_2,G_2,B_2). Input signals are RGB color values of uniform 64 stepped 5x5x5 lattice, and W_{scale} sets 0.8. Fig.5 is an example of mapping result between input signal and scaled signal.



(a)



(b)

Figure 5. An example of comparison between input signal and scaled signal (a) in G-B plane (b) in rg-coordinate

Figure 5 (a) represents the scaled 5x5 points in G-B plane when R channel is constant to 255, We can show that the scaled 5x5 points preserve vector direction in G-B plane and also none of any out-of-gamut point. Fig. 5(b) represents the scaled 5x5x5 points in rg-chromaticity. We can also see that the coordinates of the scaled 5x5x5 points are identical in chromaticity with input ones.

Test for Mapping Relation Between Input and Output Color

This section represents results of the output RGB and W signal from input RGB via the scaled RGB. In Fig. 6, input R and G are set 255 and B varies 0 to 255 with 16 step. The result demonstrates the scaled RGB values and output RGB and W signal. In Fig. 6, shapes of graph of white and RGB are depend on white extraction method as equation(10). The Approach applied here is that white extraction is firstly implemented and then output RGB is calculated.

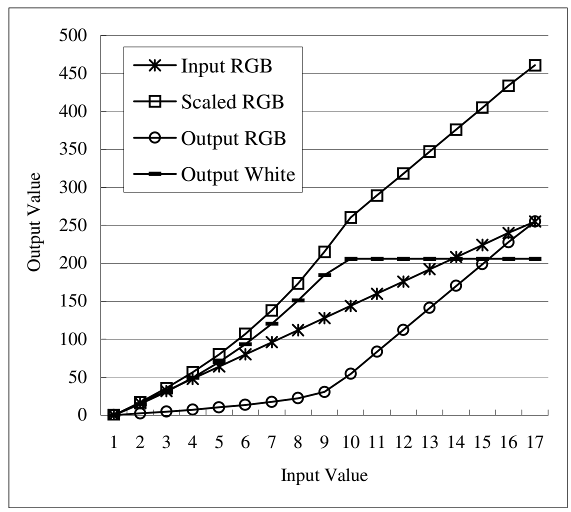
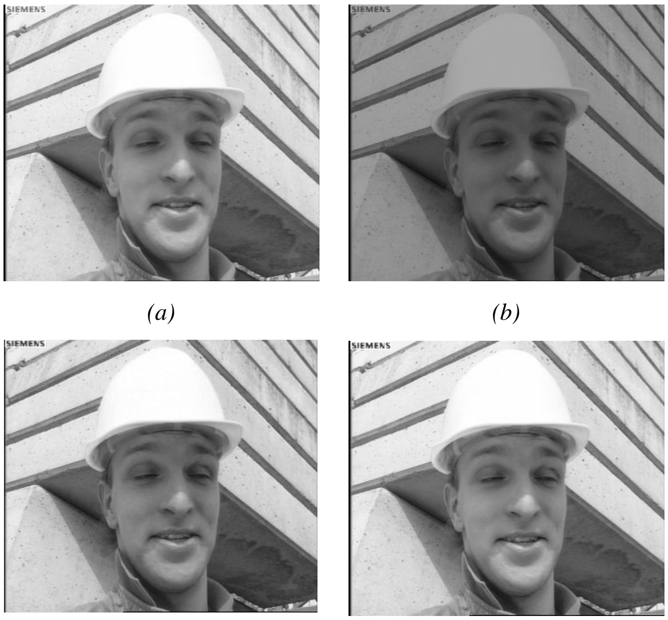


Figure 6. An example of input RGB, scaled RGB, outputRGBW signal

Image Tests

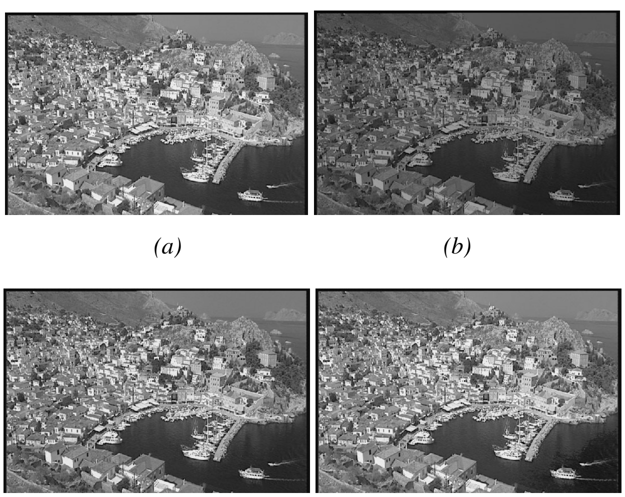
The result images applying the proposed method are demonstrated in Fig. 7 and 8. In Fig. 7 and 8, (a) is the ideal image of Forman. (b) is an image simulated by lowering brightness of image (a) by 1/3. (c) is a result image by simply adding a white channel. (d) is a result image applying the proposed method with W_{scale} = 0.5.

In Fig. 7 and 8, although (c) images have got a substantial increment on brightness compare to RGB display images (b), (c) images show color-shift to gray due to the dechromatic effect. On the contrary, (d) images demonstrate that the proposed method preserves the original color quality as well as increasing brightness. Note that (d) images have more saturated colors than (c) images.



(a) *(b)* *(c)* *(d)*

Figure 7. Examples of Foreman Image: (a) Ideal, (b) Real, (c) White Enhancement, (d) Proposed



(a) *(b)* *(c)* *(d)*

Figure 8. Examples of PortCity Image: (a) Ideal, (b) Real, (c) White Enhancement, (d) Proposed

Table 1. Comparison of the Average Y in Figs. 7 and 8

	(a) image	(b) image	(c) image	(d) image
Fig. 7	166	110	157	166
Fig. 8	157	104	156	156

Table 1 compares the average of each image in Fig. 7 and 8 by a histogram analysis in order to see the effect of brightness increment. The images generated by the proposed method (i.e. (d) images) are around 50% brighter than the images of RGB display (i.e. (b) images) and also similar to the one of ideal images (i.e. (a) images).

Conclusion

Although the RGB+White filter method increases the output light intensity to the RGB 3-filter method in projection monitor, it also degrades the saturation of input color. This paper proposes a method that utilizes RGBW color gamut to preserve the color of original images as well as increasing the output light intensity. The experimental results demonstrate that the proposed method increases around 50% of brightness compare to RGB images.

The proposed method was successfully applied to 1-panel FLCD Projection system.

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Biography

SeongDeok Lee received his BSEE and MSEE degree from the Kwangwoon University at Seoul in Korea in 1987 and 1989, respectively. In 1990, he joined Samsung Advanced Institute of Technology (SAIT), working in the areas of device calibration/characterization, reflectance recovery, illuminant color extraction, object tracking in the video sequences. he currently researches and developes the 4 channel color processing and sub-pixel rendering for improving display image quality.