Design of Mobile Display Color Control Algorithm Using Red and Blue Color Emphasis with Skin Color Protection

Jooyoung Ha*, Joohyun Kim**, Hoongee Yang***, Bongsoon Kang**** ***Regular Members***

ABSTRACT

In this paper, we propose the modified display color control system using white point line, boundary lines and S-shaped curves to emphasize blue and red tone colors on CIE1931 diagram. The proposed system divides RGB gamut into movable area and non-movable area by using boundary lines. The colors in movable area are moved into right side or left side along quadratic curve to change the bluish (or reddish) color to more bluish (or more reddish), while those in non-movable area are excepted from color control to prevent skin color from changing. The loci of the quadratic curves are very similar to the arc of the white-point line which connects all points that represent the chromaticities of a black body radiator at different temperatures and is also called the black body locus. The RGB gamut extension by movement of chromaticity coordinate can improve color reproducibility. Therefore in the case of application to LCD, the display shows excellent performance because the LCD's color reproducibility is comparatively lower than that of other display systems. The proposed system is also experimentally demonstrated with Xilinx Virtex FPGA XCV2000E- 6BG560 and the TV set.

Key Words : CIE1931, RGB gamut, White point line, S-shaped conversion curve, boundary line

Ⅰ. Introduction

In recent years, display viewers have demanded more vivid images as display technologies have progressed. When one watches a scene, one can feel the general color tone from the scene. Under an incandescent lamp, one can feel the reddish color tone whereas one can feel the bluish color tone in the case of daylight one. This feeling is different from scene to scene or image to image. This different feeling can be converted into a figure in the form of chromaticity coordinates. It can be also transformed into the daylight locus on the chromaticity plane [1-4]. A conventional color converting system changes RGB signals for hue, saturation, and so on [5], fixes the RGB to certain assumed values without considering the incoming color tones. Another system uses a gamma correction to compensate for the color distortion caused by the properties of display devices such as cathode ray tube (CRT), thin film transistor-liquid crystal display (TFT-LCD), and so on [6]. However, it still uses fixed-inverse gamma values for the compensation without considering the color tones.

New approaches to converting colors on the white point line have shown improved results [1]. They provide the facility for changing the color tones of the incoming image based on use-preferred tones. However, they also change specific colors, such as skin color [7]. This is not recommended in the color

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※ 본 연구는 2005년도 동아대학교 교내학술연구비(공모과제)에 의해 연구되었음.

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논문번호 : KICS2005-10-002, 접수일자 : 2005년 10월 4일, 최종논문접수일자 : 2006년 3월 6일

conversion system. Another problem is that same conversion ratio is applied to the every input color (or pixel) in the image. The result causes the color saturation when the colors reside close to the edges of the chromaticity coordinate diagram. In order to solve the problems, the proposed system adopts the boundary lines and S-shaped conversion curves.

The rest of the paper is organized as follows. Section II describes the details of the algorithm proposed in this paper. Section III presents hardware designs, and Section IV shows experimental results. Finally, conclusions are given in Section V.

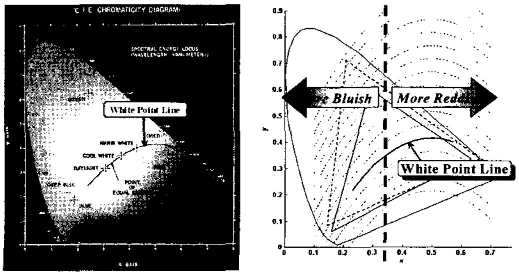
Ⅱ. Proposed algorithm

To enhance display quality without saturation and discoloration, we introduce the modified display color control algorithm. The new approach uses quadratic curves similar to white point line, S-shape conversion curve and boundary lines.

2.1 Derivation of Quadratic Curves

Figure 1 shows the CIE1931 chromaticity coordinate diagram [5]. The arc in Fig. 1-(a) is called the white point line or the Black body locus. The line represents the chromaticity coordinates of a blackbody at certain temperatures [8].

The white color is located on about (1/3, 1/3) coordinate in Fig. 1-(a). The white color position will be used as the base to measure the distance of a certain coordinate. When a coordinate resides in the left side of the line, the color temperature is high and it contains a blue tone [8]. When the coordinate resides in right side, the temperature is low and it contains a red tone. Human eyes are more sensitive to blue and red colors relative to green color [1-5]. So, this paper focuses on the emphasis on blue and red tones. Once the locations of the chromaticity coordinates on the line are measured, one can change the color tones of input images along the white-point line.



(a) CIE1931 (b) Quadratic curves

Fig. 1. CIE1931 chromaticity coordinates [5] and Quadratic curves along the white point line

The reciprocal color temperature is a linear function of distance along the arc;

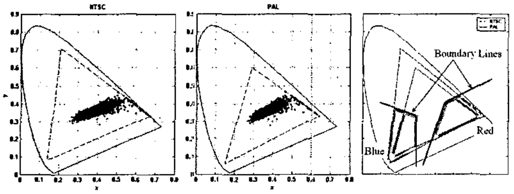
Thereby it requires very huge hardware for implementing high-precision square root, dividers, multipliers, inversions, and so on [1]. Therefore, the quadratic curves are chosen since the loci of the curves are very similar to the arc of the white-point line and the curves are relatively easy for hardware implementation.

Figure 1-(b) shows the quadratic curves (dotted lines) along the arc. The quadratic curves are easily derived by Eq. (1) where a and b are constants, and c selects one of the quadratic curves. x represents the x-coordinate value on the diagram and y represents the y-coordinate value, respectively.

$$y = -a(x-b)^2 + c \qquad (1)$$

2.2 Criterion for Human-skin Area and Decision on Boundary Lines

The input RGB signals are converted into XYZ coordinates used in the CIE1931 diagram by matrix conversion [8, 9]. The conversion is conducted whether the inputs are NTSC or PAL standards. Figure 2 shows the RGB gamut of the maximum-triangle area in the diagram. We are to measure the distributions of human skins on the chromaticity coordinate diagram. For this purpose, we used about 100-human images all over the world to get the distributions. Figure 2-(a) shows the distribution with the NTSC, and Fig. 2-(b) shows the distribution with the PAL, respectively. Based on the distributions shown in Fig. 2, we now decide the boundary lines to distinguish between the conversion and the non-conversion areas. For easy hardware implementations, we use the linear lines in Fig. 2-(c) that can exclude most of the distribution areas, while maintaining the blue and red areas for the convert-



(a) M/NTSC (b) B,D,G,H,I/PAL (c) Boundary lines

Fig. 2. Distributions of human skin's chromaticity coordinates with NTSC and PAL and boundary lines

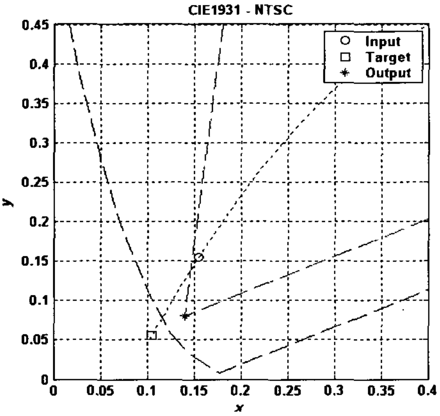


Fig. 3. Consideration on color conversion

sion. These areas are the regions of interest in this paper.

2.3 Consideration on Changing Colors

In order to change bluish colors into more bluish colors, a simple way is to multiply a chromaticity coordinate value with on the order of the distance between the colors of white and blue. Figure 3 shows an example under the NTSC standard. The coordinate of '○' represents the corresponding-RGB values of (5, 40, 200) for a coordinate near to the edge of the triangular gamut. In the RGB domain, the minimum and maximum values are 0 and 255, respectively. Since the B value of 200 is the greatest, it is likely on the left edge of the quadratic curves as shown in Fig. 3. Therefore, the distance between the coordinate and the white color is big. When we multiply the coordinate values by on the order of the distance, the resulting target values go beyond the diagram. It is denoted as '□' in Fig. 3. The result means that there is no way to represent the corresponding-RGB values since it is beyond the RGB gamut. Thus, we limit the value within the gamut. It is denoted as '*' that is on the edge of the gamut. This implies that the color is saturated under certain conditions. This causes color distortions.

Table 1 reveals the problem. The target values are (-60, -14, 691) that are beyond the minimum and maximum values. The third column shows the limited values of (0, 0, 255) that imply color distortion.

Table 1. An example of a linear-scale color conversion with RGB values

	Input	Target	Output
R	5	-60	0
G	40	-14	0
B	200	691	255

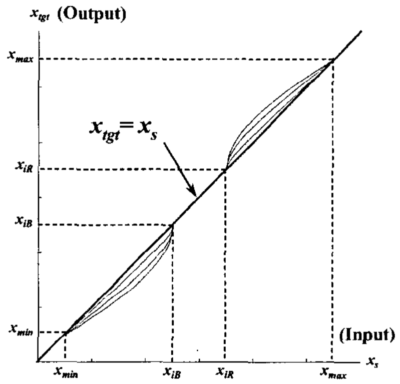


Fig. 4. S-shaped curves

2.4 S-shaped transfer Curves

In order to avoid the color distortion shown in Ch. 2.3, a means has to be developed. This paper develops S-shaped transfer curves. Figure 4 shows the curves. The x-axis represents input x-chromaticity coordinates and y-axis represents target x-chromaticity coordinates. The x_{max} and x_{min} are the maximum and minimum values of the chromaticity coordinates on the RGB gamut. The x_{iR} is the starting point of the S-shaped curves into the red area and the x_{iB} is the starting point into the blue area, respectively. When $x_s = x_{tgt}$, the location is the area of the white color in the CIE1931 diagram where human-skin tones reside as shown in Fig. 2. Thus, we use two-different values for the starting points in the color conversion system proposed in this paper. The S-shaped transfer curves used are

$$- \sqrt{\frac{(x_{min} - x_{iB})(weight)(x - x_{iB}) + (x - x_{iB})^2}{weight + 1}} \quad \text{for } x_{min} \le x_s < x_{iB} \qquad (2)$$

$$\sqrt{\frac{(x_{max} - x_{iR})(weight)(x - x_{iR}) + (x - x_{iR})^2}{weight + 1}} \quad \text{for } x_{iB} \le x_s \le x_{iR} \qquad (3)$$

where weight is one of (4, 1, 1/4, 0). When weight is 0, the S-shaped curve has the biggest winding in Fig. 4. To simplify the equations, the following conditions are adopted:

$$x_{maxmin} = x_{\min}, x_i = x_{iB} \quad \text{for } x_{min} \le x_s < x_{iB} \qquad (4)$$

$$x_i = x_s \quad \text{for } x_{iB} \le x_s \le x_{iR} \qquad (5)$$

$$x_{maxmin} = x_{max}, x_i = x_{iR} \quad \text{for } x_{iR} < x_s \le x_{max} \qquad (6)$$

where x_{maxmin} denotes the intersection between the triangular RGB gamut and quadratic curves, and the x_i denotes the starting point for the S-shaped curves. By using Eqs. (2) and (3) with Eqs. (4) through (6), we get the target x-chromaticity coordinate

$$x_{tgt} = \pm \sqrt{\frac{(x_{maxmin} - x_i)(weight)(x - x_i) + (x - x_i)^2}{weight + 1}} + x_i \qquad (7)$$

By inserting Eq. (7) into Eq. (1), we get the corresponding y-chromaticity coordinate

$$y_{tgt} = -a\left(x_{tgt} - b\right)^2 + c \qquad (8)$$

By using the S-shaped curves with weight = 1/4, we also test the RGB values of (5, 40, 200) as was in Table 1. Table 2 shows the results. The resulting target values are (3, 39, 213). The values are within the minimum and maximum values. The third column is the RGB values obtained from the proposed system that are equal to those of the target. Thus, one can see that the proposed system does not distort the converted images [see Table 1 and Table 2].

Table 2. Resulting RGB values of the proposed color-conversion system

	Input	Target	Output
R	5	3	3
G	40	39	39
B	200	213	213

Ⅲ. Hardware designs

Figure 5 shows the block diagram of the proposed system. The proposed system is comprised of twelve major building blocks. The input and output signals used in hardware designs are the International Telecommunication Union-Recommendation (ITU-R) BT.601 4:2:2 [10]. The *YCbCr2RGB* converts the YCbCr signals into the RGB signals. The *RGB2XYZ* converts the RGB signals into the XYZ signals used in CIE1931 chromaticity-coordinate diagram with the NTSC and PAL standards. The chromaticity converts the XYZ signals into the chromaticity coordinates of (xs, ys). The *cxypos* decides the y-intercept in Eq. (1) and the position of the input signals on the CIE1931 diagram as shown in Fig. 2. The *xMaxMin* finds the x_{maxmin} in Eqs. (4) and (6). The *xintersection* finds the x_i in Eqs. (4) through (6). The *Target_xy* calculates the target values in Eqs. (7) and (8). The *XoYoZo* converts the chromaticity coordinates of the target (x_{tgt}, y_{tgt}) into XYZ signals. The *XYZ2RGB* converts the XYZ signals into RGB signals. The *RGB2YCbCr*, then, converts RGB signal into the ITU-R BT.601 4:2:2 signals for display systems, such as TV set, and so on. The proposed system is designed by using Verilog-HDL models. The models are synthesized into gates to see the hardware complexity by using the Synopsys synthesizer with the TSMC 0.25-um library. The total gate

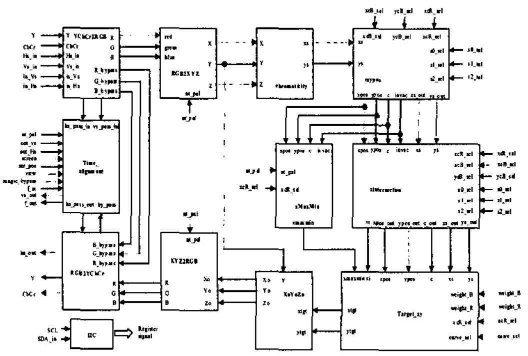


Fig. 5. Block diagram of the proposed color conversion system

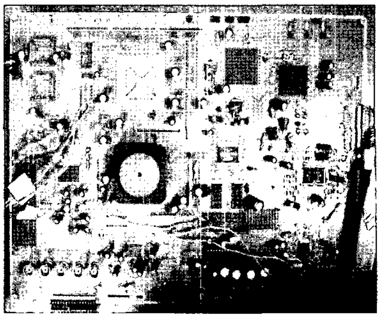
count is 271,469 gates where a 2-input Nand is counted as one gate. The proposed system is activated in a single clock of 27 MHz.

Fig. 6. Simulation results of the proposed system

Ⅳ. Experimental results

Figure 6 shows the resulting images obtained by using the system proposed in this paper. The left side of the image shows the input image and the right shows converted images obtained by using the boundary lines and S-shaped conversion curves proposed in this paper. As you can see, the background bluish color becomes more bluish in the right and the reddish-color skirt of the woman becomes more reddish in the right. Thereby, more reddish and bluish colors can be achieved by using the proposed system without any color distortion. The design is also verified by implementing the hardware with the Xilinx Virtex FPGA XCV2000E-6BG560. Figure 7-(a) and (b) show the demonstration PCB board and the demonstration TV set utilizing the demonstration board, respectively. The left side of the scene in Fig. 7-(b) shows the incoming video (bypass), and the right side shows the converted video using the proposed system. Once again, we see that the red color becomes more reddish and the blue color becomes more bluish without any distortion.

We also see that human-skin tone is not changed by using the boundary lines as shown in Fig. 2-(c). Thus, Fig. 7-(b) proves the effectiveness of the proposed system.



(a) Demonstration board

(b) TV set

Fig. 7. Demonstration PCB board and TV set of the proposed color-conversion system

Ⅴ. Conclusions

In this paper, we proposed the advanced color conversion system using white point line, boundary lines and S-shaped curves. The boundary lines distinguished the movable areas from non movable areas containing human-skin tones. The S-shaped curves avoided the color distortion with saturation. The colors in the conversion areas varied along the quadratic curves, and the curves are relatively easy for the hardware implementation. Thus, the proposed system can control and emphasize colors without any color distortion by moving positions of the colors toward left or right on the quadratic curves, while skin colors are excluded from the conversion. Therefore, this proposed system can be applied to various display systems, such as TV, camcorder, TFT-LCD, and so on. In the case of application to LCD in particular, the display shows excellent performance because the LCD's color reproducibility is comparatively lower than that of other display systems [11].

Acknowledgement

The authors wish to thank the IDEC for its software assistance. This work is the result of IT-SoC 2005 Practices Project that is supported by the Korea IT Industry Promotion Agency (KIPA). This paper is supported by Dong-A University's research expenses in 2004

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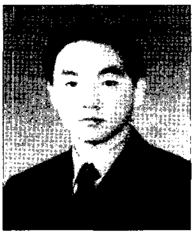

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