Presenting surface colors on computer controlled CRT displays

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ABSTRACT

It is well known that CRT displays have limited color presentation capability. In everyday cases the drawback mainly shows up in the DTP field where the color space of displays does not match the printers' color space, thus the color presented on the display does not correspond completely to printed color.
In the contrary case the aim is to present painted surface color on a computer display. Due to the narrow color space of CRT displays direct matching of colors that fall outside of the display's color space is impossible based on CIE xyY color system. When transferring surface colors to displays there are tasks for which not only color matching, but also spectral matching is vital. In "display as measuring device" type of tasks, such as color deficiency diagnosis with painted tests transferred to computers, enabling maximal correspondence of both parameters is important, because color deficiency is caused by spectral degeneration of the sensitivity of the eyes.

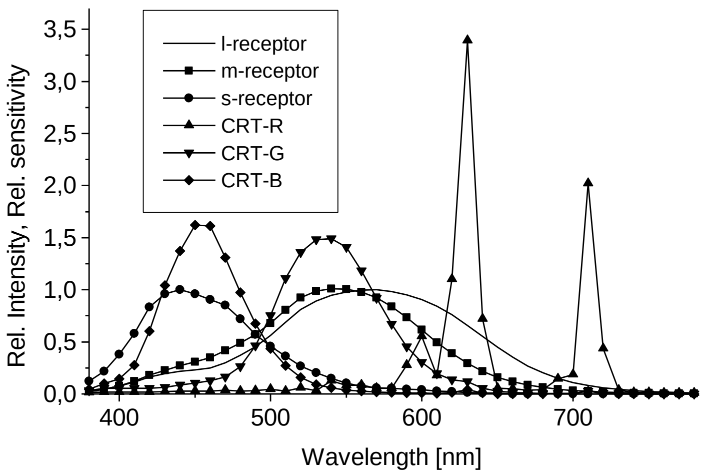
1.INTRODUCTION

The usage of computer controlled CRT displays as color displaying devices or measurement tools has two theoretical limitations. These are (a) narrow color space display range and (b) not ideal spectral emission of CRT display primaries.

a. Most frequently used CRT displays today utilize a version of phosphorus P22 (Figure 1.) that radiates in its red, green and blue band. The x,y values calculated from the spectral emission of R, G and B phosphorus (Figure 3.) cut out a triangle from the CIE xy diagram that we call the color space of CRT displays. It is obvious that the color space of a CRT display in CIE xyY color diagrams representing all colors perceivable by a human eye is very limited.
b. Spectral emission characteristics of a CRT display containing phosphorus P22 and human eye sensitivity characteristics provided by Pokorny and Smith [7] are depicted in Figure 1. The distribution and peak of Gauss-curve shaped blue and green primaries fit human eye sensitivity characteristics quite well. Therefore any arbitrary eye stimulation condition can be generated with great efficiency in the blue-green range of the visible light. The spectrum of the red primary on the other hand, shows a strong stripe pattern, and differs from the sensitivity profile of the eye's red receptors. It is hard to produce an arbitrary stimulus condition here. The task gets even more difficult when we account for the fact that the main cause of color deficiency is the red or green characteristic's (Figure 1.) shift to the right or left. If we want to set up our color matching method in a way that will enable it to account for this phenomenon, it is necessary to add spectral analysis to the color matching procedure.

The practical application of CRT displays is necessarily limited by calibration as well. If we want to use a CRT display as a measuring device we have to calibrate it as such. CRT display measurements require serious practical preparations due to the fact that photometric calibration of CRT displays, besides simple geometric calibration, involves assigning mutually independent parameters (Gamma, CCT, luminosity-contrast). [3]

Figure 1.: Emission spectrum of CRT displays containing phosphorus P22 and sensitivity characteristics of the receptors of the human eye



The number of colors that can be presented in a CRT display's color triangle is discrete and finite due to the nature of digital technology. Currently widespread types of video hardware can produce 2^{24} colors in any given color triangle, although there are already hardware models on the market capable of producing a resolution of 2^{32} colors. Computer video systems that generate color with three primaries (R, G, B) can channel some primary colors with an 8-bit resolution, and that means producing R, G and B primary colors on a 256 luminosity level. With the combination of these primary colors we can generate 256^3=224≅16,8 million colors in the three-coordinate RGB color space of CRT displays. The R, G and B coordinates of thecolor that we wish to present on the CRT display can be programmed by software. The measurement unit of the color coordinates is DAC that can take the value of any integer between 0 and 255. It is important to note that the relationship between DAC and luminosity density (L[cd/m^2]) appearing on the display is exponential and depends on the current calibration of the CRT display.[5]

When presenting surface colors on CRT displays, our goal is to find the appropriate color among the 16,8 million colors of a CRT display's color space, that will fall closest to any given surface color that we wish to display both in terms of its spectral content and in accord with color difference $\Delta E^*_{a,b}$ defined by CIE. [1,4]

2. METHODS

The optimal transfer of surface colors onto CRT displays was done using Labview computer simulation. The optimal CRT display color had to be picked out of 16.8 million, justifying computer analysis because its search algorithm consisted of 16.8 million cycles. The transfer algorithm of surface colors to CRT displays is depicted in Figure 2. The initial data are functions of the gamma characteristic and the spectral emission of the RGB-channel that we have gotten from CRT display calibration. These parameters help us generate the total spectrum (16.8 million) that can be presented on a CRT display.

The 85 color patterns of the Farnsworth test [2] were measured by a reflexive spectrophotometer that uses D65 reference white. The already available color sample spectrum and the CRT display spectrum were compared by MSE and CIE Lab color difference calculation ($\Delta E^*_{a,b}$). By multiplying the two values with autonomously converging weight coefficients m and n, we can generate an error term, due to the fact that both the MSE value of the spectrums and the $\Delta E^*_{a,b}$ value indicate color difference. After that the main cycle of the algorithm checks whether the error of the CRT color is smaller than the current minimal error, and less than the color-discrimination threshold of $\Delta E^*_{a,b}$ =1,4, and if so, the current DAC value becomes the optimal solution. In any other case we retain the previous $(R,G,B)_{DAC}$ value.

Initial data consisting of CRT spectrums were measured by an Instrument Systems CAS 140B spectrophotometer, while the display and gamma characteristics were measured by a calibration device that we designed [6]. Visual background consisted of an LG 55i CRT display and a Matrox Millenium G450 LX graphic card.

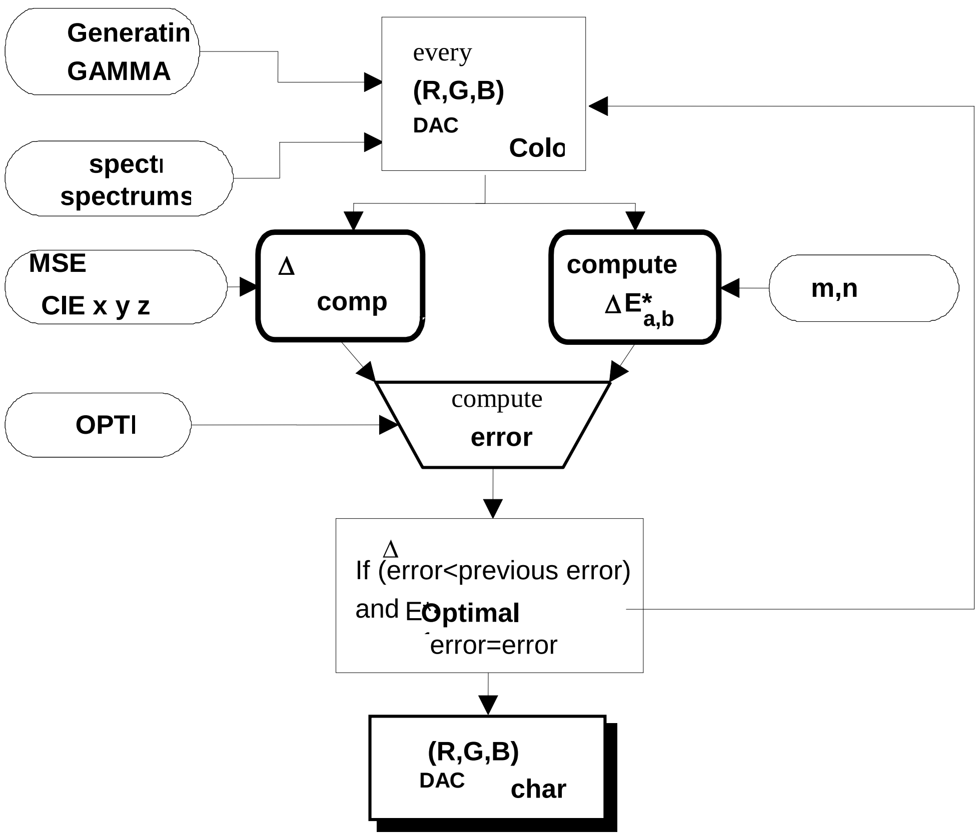


Figure 2.: Algorithm of the optimization procedure

3. RESULTS

Despite computer analysis, the transfer of the Farnsworth 100 Hue test's 85 color pattern cap to the CRT display's color space took a significant amount of time. Matching a single color takes about 10 to 15 minutes on a Celeron II 800MHz computer. Computing time can be decreased by 20-25% if we increase the DAC-stepsize embedded in the algorithm, and make the DAC threshold adjustable.

Figure 3: Color presentation capability of a CRT display containing P22 phosphorus, and the ellipse of the Farnsworth 100 Hue test's color stimuli in the CIE 1931 xyY diagram

Table 1. shows the results of five color-matching Farnsworth tests. The five presented colors (Farnsworth test for 15, 30, 45, 60 and 75 color pattern caps) originate from different parts of the ellipse embedded in the CIE xyY coordinate system that contains all color patterns (Figure 3). The x,y columns of Table 1. list the color coordinates of these test caps.

No.	x $[\cdot 10^3]$	y $[\cdot 10^3]$	Surface color → DAC								Spectral MSE	
			Optimization for $\Delta E^*_{a,b}$ (A)				Total optimization (B)					
			R	G	B	$\Delta E^*_{a,b}$	R	G	B	$\Delta E^*_{a,b}$	(A)	(B)
			[DAC]				[DAC]				[rel. units]	
15	426	422	192	146	55	0,15	187	142	50	1,31	0,452	0,895
30	322	402	121	169	106	0,11	117	165	102	1,39	0,284	0,247
45	251	326	56	160	152	0,22	53	157	148	1,11	0,181	0,158
60	259	263	106	150	186	0,14	103	146	181	1,38	0,433	0,388
75	330	278	183	132	153	0,15	178	129	148	1,39	0,984	0,903

Table 1: Comparison between optimization for $\Delta E^*_{a,b}$ and total optimization ($\Delta E^*_{a,b}$ + spectral MSE)

Optimization was conducted in two ways to show how effective the new method is. Besides the total optimization algorithm ($\Delta E^*_{a,b}$ + spectral MSE) that we developed, we also ran optimization strictly on color differences ($\Delta E^*_{a,b}$). As expected, the latter algorithm yielded $(R,G,B)_{DAC}$ values that were closest to the Farnsworth cap color coordinates. These matchings can be found in the RGB columns of the fourth column set (noted as A). The $(R,G,B)_{DAC}$ values of individual caps were computed with a very small $\Delta E^*_{a,b}$ difference, because even the highest value (0.22) is below color discrimination threshold.

Color differences computed by total optimization from $(R,G,B)_{DAC}$ values listed in column set B clearly approach the still acceptable $\Delta E^*_{a,b}$=1.4 threshold value. Thus, we were able to fully exploit the spectral space around the x,y coordinates of the Farnsworth color patterns given $\Delta E^*_{a,b}$ =1.4.

This is supported by the last two columns that contain MSE values of the difference between spectrums calculated from $(R,G,B)_{DAC}$ values optimized with two methods (A, B) and spectrums of the original color pattern caps. Excluding color pattern 15, total optimization produced smaller MSE, which means that spectral similarity between the original pattern and the display color increased. For cap 15, high MSE values appeared because of the discrete color spectrum’s distortion effect on MSE, however, figure 4.a clearly shows that the curve generated by total optimization follows the shape of the original surface color’s reflexive curve.

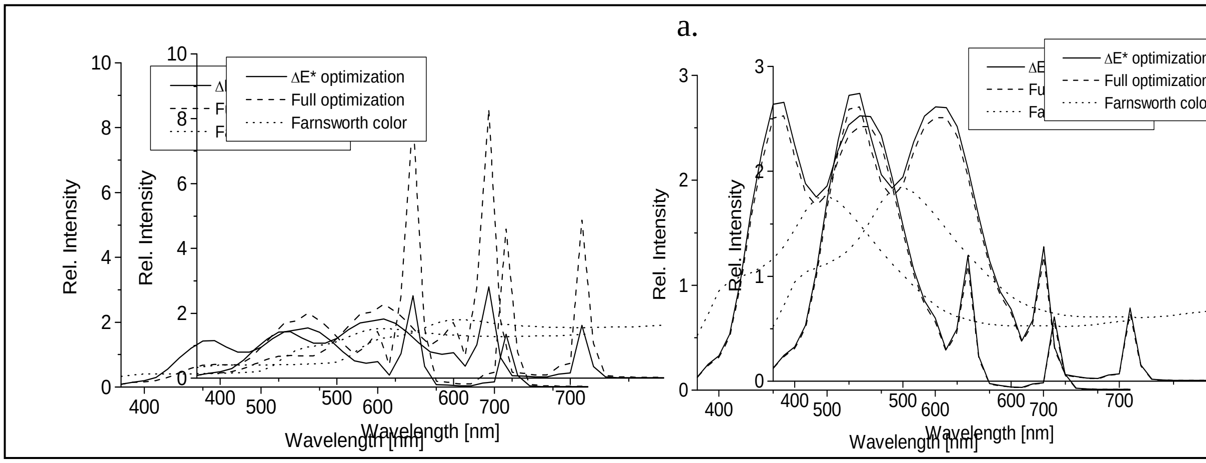


Figure 4: The reflexive spectrum of Farnsworth cap 15 (a) and cap 45 (b) in comparison with partially and totally optimized $(R,G,B)_{DAC}$ emission spectrums

4. CONCLUSIONS

In table 1 it was shown that the newly developed surface color to CRT display color matching method uses the interval provided by $\Delta E^*_{a,b}$ to its full capacity in the search for alternative emission spectrums for color matching. It facilitates spectral matching which is important in color deficiency diagnostics, or other applications that require spectral approximation.

From Figure 4a it is clear that our method has a significant spectral approximation effect in the red-green range which is important for color deficiency diagnostics. This is also supported by comparing original patterns with partial and total optimization.

It can be concluded that the method for optimal transfer of surface colors to CRT displays takes into account spectral as well as colorimetric matching, and improves the transfer quality of printed and painted color deficiency diagnostic tests to CRT displays more than earlier methods [8].

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