Modified Error Diffusion for Color Correction

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Abstract

In this paper, modified error diffusion algorithm for color-correction is proposed to solve the problem of inherent color distortion and the limited number of output colors for display devices. The proposed algorithm combines the two processes of error diffusion and color correction for simple and efficient implementation. The two processes can be operated simultaneously for the correction of color distortion in a display device which has limited output colors.

The most important aspect of this algorithm is to handle color correction factor in the error diffusion process.

Color correction of this algorithm has two phases, compensation for gamma characterestic of display device and color distortion. The former term is related to the non-linear characterestic of display device, and the latter for linear color distortion. For simple implementation, color correction factor can be considered in the error diffusion process by introducing color correction LUT to the calculation part of diffusing error values. By using this implementation, one can control the color characterestic of display devices and virtual number of output colors simultaneously.

Introduction

Color correction is necessary for display devices, because the input signal can be distorted for the systematic characteristics when they are displayed. And this is the common problem for most display devices. Especially, if the number of output color is limited for some device, it is very difficult to present correct data on the display because two factors of quantization and color distortion have influence on that device simultaneously.

To solve this problem, the model for considering the two factors simultaneously is needed, we proposed an error diffusion algorithm with color correction, which consists of two modules; error diffusion and color correction process. Error diffusion process[1] can represent maximum detail of input images in devices with limited output colors. And color correction process compensates the color distortion of arbitrary display devices. These two modules can be implemented by each independent processes and connected sequentially for the total system, or implemented to single process by combining the two processes. In case of the former one, it is more accurate, but the corrected values for the color correction process are different from the quantization steps for the device output. Since the most devices have limited output colors, color correction method can not be applied to such devices directly. For the latter one, it is possible to apply the combined model to such devices directly and free from the quantization step problem in the color correction process. For the implementation of combined model, the error values to be diffused in the error diffusion process should be determined with consideration of corrected values of color correction process.

Color correction process can be modeled as two parts of linear and nonlinear ones. The linear one is related to the linear color distortion of the display and the nonlinear one represents the gamma characteristic of the display. To have the gamma values of each RGB channel for the device, some levels for each primary colors were displayed on the device and Y values from the measured Yxy were used in the computation of gamma values. After that, we have gamma values, the gamma-correcting primary values can be obtained for each channel and it called device-RGB with gamma-corrected. For next step, the device-RGB with gamma-corrected were applied to the display and the output Yxy can be measured. These measured output represents the linear color distortion for the device without the effect of gamma characteristic. Now we have gamma for the nonlinear part and another measured values for the linear part. In this case, color correction method such as linear I/O regression[2] can be used for the modelling of linear color distortion. The correction values for the linear color distortion part can be obtained by considering the relationship of I/O mapping of known data. By this computation, the relationship between device-RGB with gamma-corrected and output device-RGB is obtained.

And the nonlinear part should be considered next, the correction values for the linear distortion has scale factor proportional to the gamma compared to the source-RGB. Because there exist gamma factor between source-RGB and device-RGB with gamma-corrected. The relationship between source-RGB and device-RGB with gamma-corrected should be considered to combine the two processes. By considering this relationship, the scale factor can be properly adjusted for the error values of the error diffusion process. The scale factor means that there exist this factor between source-RGB in which error diffusion is performed and device-RGB with gamma-corrected. To consider the color correction values in the error diffusion process, compensation of this scale factor is important.

We used LUT (Look-Up Table) for simple implementation because we can compute the color correction values for each quantization steps in the error diffusion process in advance. In this paper, we proposed very simple and efficient architecture for the simultaneous processing of color correction and error diffusion.

Models

In this section, the models for color distortion, color correction, error diffusion and other related models will be considered. Also, the combination of color correction and error diffusion, and model for device with limited output colors will be discussed. Color correction process can be modeled as two parts of linear and nonlinear ones. The linear one means linear color distortion of the display, and nonlinear represents the gamma characteristic of the display and is shown in Figure 1.

In Figure 1, D denotes the linear color distortion function and γ_f means forward gamma value of the display device for each RGB channel. The distortion function can be obtained from the relationship between input and measured output.

The next is the color correction model that corresponds to the above color distortion model. By taking the inverse function of D and calculate the backward gamma values γ_b from γ_f, color distortion can be corrected, and the model is presented in Figure 2.

The above color correction model can be applied to the devices with continuous output levels, but in many cases, most devices have limited output colors. The above model can not be applied directly in such case. The proper model for the devices with limited output colors can be considered as follows. Though, the color corrected value for the linearized output is known, the possible output we can take are limited by some colors. This situation can be modeled to color correction model with output quantizer as in Figure 3. And there exist correction errors for the quantizer, this quantization error should be compensated in the processing of input stage for efficient color correction. The modified model is presented in Figure 3.

Error diffusion process is very efficient method with the effect of representing more information with the limited output colors. A simple model for error diffusion is presented in Figure 4. The main idea of this process is preserving the average values for the local region.

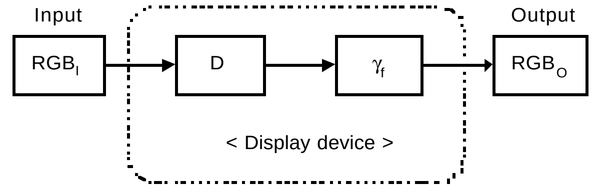

Figure 1. Color distortion model

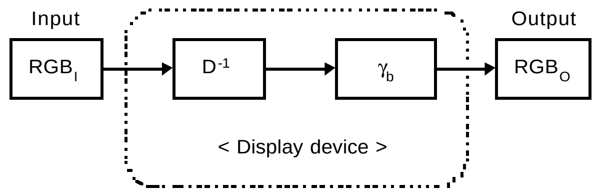

Figure 2. Color correction model.

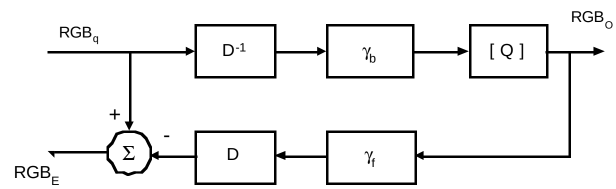

Figure 3. Color correction model for the devices with limited output colors.

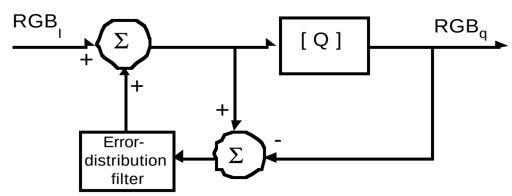

Figure 4. Error diffusion model.

The error diffusion and color correction model with output quantizer can be combined to single process as presented in Figure 5. The error values to be distributed can be replaced by transformed quantization error of color correction process. Color correction error can be considered in the error diffusion by this transform, so the function takes the inverse processes of the color correction that is, color distortion process.

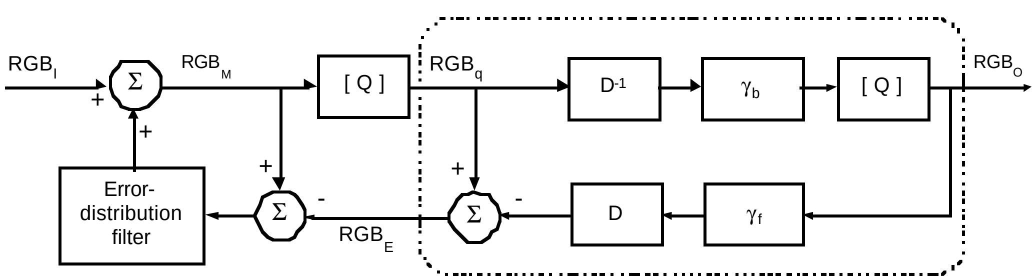

Figure 5. Combined model of error diffusion and color correction.

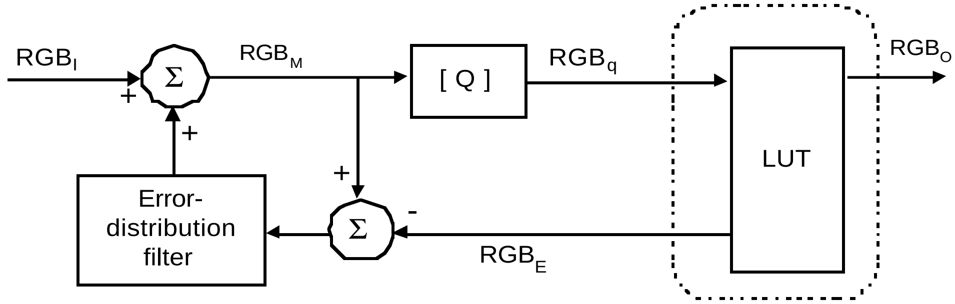

Figure 6. Equivalent combined model of error diffusion and color correction.

It is not so easy to implement the color correction part of Figure 5 for the nonlinear data mapping and processing time. The equivalent model can be made and it is very simple to be implemented because the related values are pre-computable for the limited output colors. And the color correction function can be replaced by a LUT that contains color correction data for quantized output colors RGBq as shown in Figure 6.

Calculation of Distortion Function

In this section, the method for calculation of color distortion function in Figure 1 is described. To model color distortion function in simple form, it can be divided into linear and nonlinear part. If nonlinear part is contained in the distortion, the mapping of input to output is very difficult. In some cases, the proper solution could not be found for the oscillation or divergence of the mapping function. The main component of nonlinear part is assumed as gamma characteristic of display device, and for linear part, the transfer function as 3×3 linear color transform matrix which transforms one color vector to another vector. It is easy to measure output values on some display device for the predefined set of input values. First, linear and discrete values for each RGB channel are displayed on the device and the corresponding output values can be obtained by measuring them. From this, device gamma values can be calculated for each RGB channel by the method of linear regression or other mappings. Once device gamma values are known, the gamma-correcting modified input values can be computed and it is named as gamma-corrected input.

Next, this set of gamma-corrected input is applied to the device, and the set of measured output values is obtained and it is named as linearized output. The relationship between gamma-corrected input and measured values and linearized output values gives a linear part of the color distortion function. The calculation of this relationship is as follows.

For the calculation of the relationship, linear regression method is applied to the sets of input and output data values. And this method is powerful when I/O values are linear, but, even though we excluded the nonlinear part from the color distortion, the remained linear part is not so linear for the application of linear regression. Sometimes the linear regression could not be converged and the cost function oscillates or diverged. To avoid this problem, the data set is divided into several groups with similar properties, so that the piece-wise linear regression can be applied to the target data sets. The calculated relationship for linear part are 3×3 linear color transform matrixs for each group and let this matrixs as D_G, where G means the group index. The method for division of groups are based on the distribution of the measured output values in the RGB color space. In our experiment, we divide the total set into 6 groups based on hue components of data set, the main colors for each groups are R-G-B-C-M-Y.

The relationship of input and output can be represented as follows in Equation 1.

$$O_G = D_G I_G$$

O: output, I = input and G: group index, G = {1,2,.,6}.

From the O_G and I_G data sets, linear color distortion DG can be obtained by manipulation of Equation 1. The data set IG has the dimension of $3 \times N$, where N is the limited output colors, and each color vector has 3 components of R,G and B. For this data set, I_G–1 can not be computed directly because this $3 \times N$ matrix is not rectangular. But the data matrix can be changed to rectangular by multiplying $N \times 3$ transpose matrix on each side of Equation 1.

$$O_G\, I_G^T = D_G I_G I_G T \qquad (2)$$

$$D_G = (O_G\, I_G T)(I_G I_G T)^{-1} \qquad (3)$$

By Equation 2 and Equation 3, the linear color distortion function D_G for each 6 group can be obtained and, with gamma values, the total color distortion can be modeled.

Error Diffusion with Color Correction

Conventional error diffusion method is modified in structure for the simultaneous operation of error diffusion and color correction. The quantization value of Figure 4 is replaced by color correction residual components as in Figure 5.

Let input as RGB_{Iij} where, i and j mean ith row and jth column in the input image space. And modified value in the error diffusion process as RGB_M, color correction error RGBE, quantized value as RGB_q.

The modified value RGB_M can be represented by the sum of input image RGB_I and distributed error values from error diffusion filter as Equation 4.

$$RGB_{mij} = RGB_{Iij} + E'_{ij} \tag{4}$$

The notation Q denotes the quantization operation for scalar values of RGB where (p+1) is the total possible output levels s is quantization step and d is input value width for each quantization step. Quantized RGB_q is as follows:

$$RGB_{qij} = Q(RGB_{Mij}) = s\sum_{n=1}^{p}(RGB_{Mij}) - nd). \tag{5}$$

The error to be distributed is E_{ij} for each pixel and this is the difference between modified values and color correction error. By this error values, the two processes of color correction and error diffusion can be combined.

$$E_{ij} = RGB_{Mij} - RGB_{Eij} \tag{6}$$

The distributed error values can be determined by the error distribution filter and Floyd-Steinberg 4-point filter was adopted in this algorithm. The weight W = (1/16) {7, 1, 5, 3} and presented in Figure 7.

$$E'ij = WE_{ij} \tag{7}$$

Experimental Results

The proposed algorithm was tested on the notebook computer with STN-LCD panel and input image were 5 bits data for each RGB channel that makes 32768 total colors and, only 64 colors could be displayed simultaneously on the notebook. Yxy data for all 64 input color set could be measured, and it was normalized with Y value of the device white. Linear regression was applied to the normalized xyz set and source-xyz, where source-xyz were transformed one from source-RGB to XYZ space. From these two xyz data set, linear color distortion and gamma for each channel could be calculated. By this, correction values could be found for the combined model of Figure 5. The comparison of NTSC-C gamut and gamma-corrected output in xy-plane is presented in Figure 8. The non-uniform color distribution of the inner triangle showed linear color distortion as mentioned above. The correction data were regarded as LUT in Figure 6. Sample color image was processed with this algorithm and displayed on the screen of notebook computer. In general, the processed image was better than the simply quantized image or error diffused images with no color correction.

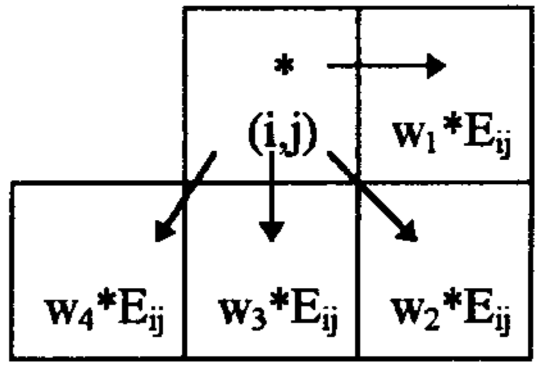

Figure 7. Error diffusion filter

Conclusion

In this paper, modified error diffusion algorithm for color-correction is proposed to solve the problem of inherent color distortion and the limited number of output colors for display devices. The combined model has two processes of error diffusion and color correction. The most important aspect of this algorithm is to handle color correction factor in the error diffusion process and one can control the color characterestic of display devices and virtual number of output colors simultaneously.

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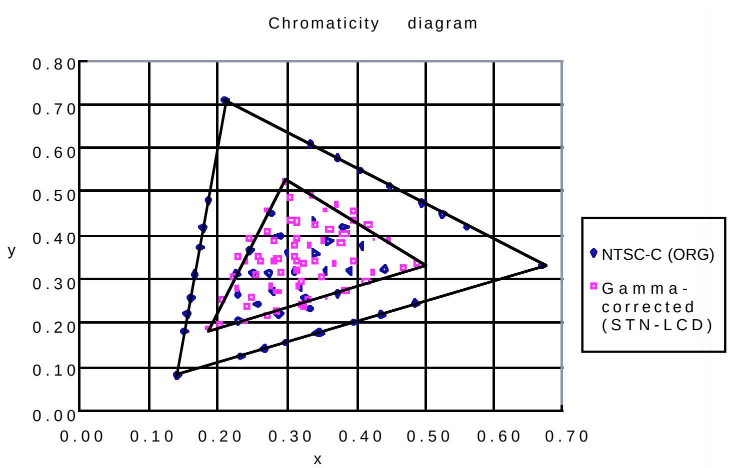

Figure 8. The gamut of gamma-corrected display values