Color Conversions In The Transform Domain

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Abstract

A noval novel technique is described for high speed color conversions for JPEG-compressed images. The color conversion is processed in the transform domain instead of the traditional spatial domain. Only the input DC coefficients of the multiple color components are processed through the traditional table lookup to create output DC coefficients. Given each output color component's DC value, the linearity of its 63 AC coefficients is determined and their transform domain scaling functions are looked up in a 1-D table as a function of only the component output DC term. For n-dimensional input color space to m-dimensional output color space conversion, n component blocks create m output blocks. These blocks can be inverse DCTed to create spatial domain data or requantized and entropy encoded to create JPEG compressed data. Abort criteria also have been developed to determine when the traditional spatial domain interpolation needs to be done.

Introduction

This paper describes for the first time a new technique for high speed color conversion[1] when the input image is DCT-based JPEG-compressed in a different color space than the desired output color space. Traditionally, these images are entropy decoded, dequantized, and then for every three (RGB, CIELAB) or four (CMYK) blocks representing 64 output pixels are inverse Discrete Cosine Transformed (IDCT). Then the spatial domain pixels are nonlinear color converted into the output pixels with four components each. Details of the JPEG compression and the Discrete Cosine Transform (DCT) can be found in reference [1].

An alternative method for doing high speed color conversions is described. Instead of reconstructed the output pixels in the spatial domain, the color conversion is done in the transform domain. Only the input DC coefficients of the multiple components are always processed through the traditional nonlinear interpolation using multidimensional lookup tables to create output DC coefficients (e.g., proportional to the component block average). Then the local linearity assumption allows the AC coefficients to be processed in the transform domain. The scaling factors (i.e. weighting functions) are determined by a simple look-up from the output DC coefficient for each component. Once the output component blocks have been created, they can be inverse DCTed to create spatial domain data or requantized and entropy encoded to create JPEG compressed data.

Wober et. al [2] uses the DCT to compress the color conversion lookup table. He found that only a few coefficients were sufficient to reconstruct the table values. That could be combined with this new technique to further reduce the storage requirements.

This paper also shows how the criteria for when to abort the linear processing can be determined solely from the DC value for each component and independently of the other components. Also this is the first example of actually determining the color component scale factors for each output color component and showing that the scale factors can be determined from the input to output ratios of each component independently for most of the output range.

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Methodology And Experiements

The methodology accurately converts the DC components of the input color blocks into the DC components of the output color blocks. The example given here is CIELAB to CMYK conversion. The block average for each component is correctly rendered using traditional linear interpolation method.

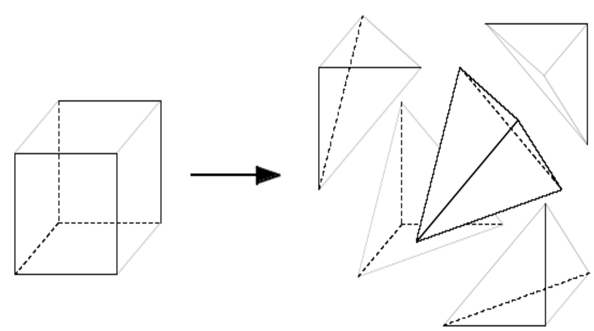

***Figure 1**. Illustration of tetrahedral linear interpolation*

Figure 1 shows the tetrahedral interpolation used to interpolate a three component input color space (CIELAB) to a printer output color space (CMYK). Color conversion from one color space to another is a CPU cycle intensive conversion and is traditionally done as nonlinear interpolation in the spatial domain using multidimensional lookup tables (LUTs) per pixel. Between the table entries, the data is assumed to be locally linear. If done for every pixel, instead of just once per block, this process is potentially a bottleneck for full color high speed printers.

[1] Patents have been applied for.

For some region around the converted DC components the color conversion is assumed linear. Linear operations in the real space can be moved into the same linear operations in the transform space. For each color component output block, the appropriately scaled nonzero AC components are summed to create that component's output block. The resulting output color component blocks can either be JPEG compressed or go through the inverse DCT transform.

Overdetermined linear system

Consider an overdetermined linear system of the form

$$Ax = b \tag{1}$$

Where $A \in \Re^{nxm}$ with $n > m \geq 2, b \in \Re^n$

In general, these will not have a solution in the sense that one gets exact equality for each equation. We hope to find a vector of $x \in \Re^m$ such that the equations are as close to being satisfied as possible, i.e., the residual vector

$$r(x) = Ax - b \in \Re^n \tag{2}$$

is as small as possible.

The most popular method to solve overdetermined linear system is least squares. There are many algorithms to solve the least squares problem, such as QR factorization and SVD.

When an input color space is converted to an output color space, there often exist many input values to one output value mappings. For example CMYK to gray conversion, the number of input CMYK values (assuming 17x17x17x17 lookup table) is 17x17x17x17, and the output gray levels are at most 256. Therefore color conversions from CMYK to K at most of gray levels in the output are overdetermined systems. If we could find vector x for each output level such that the residual defined in equation 2 meets a predetermined threshold, then we can conclude that the color mapping at that level is linear.

Color to gray conversion

As a special case of the color conversion problem, there is a need for fast, efficient color conversions from CMYK to monochrome grayscale. This allows customers to start preparing for color and yet still printing on their monochrome printers. They create their documents in color and for the monochrome printers the colors are converted to monotone grayscale. The Advance Function Presentation (AFP) data stream is being made ready to handle color via the AFP Color Consortium.

Swop (specification for web offset printing) data that map from the standard CMYK to CIELAB was used in our color to gray conversion experiment. CIELAB value for each input CMYK is converted to lightness. That is then mapped to the level of grayscale. There are two steps to determine the linearity: first step is to find the output levels where the color mappings are overdetermined systems. And the second step is to apply numerical analysis method (for example least squares method with SVD approach) to the data to determine the scaling factors. The perception data is then converted to gray values K’.

This new technique accurately converts the DC components of 4 blocks containing one component of C, M, Y, and K each into the DC component of an output K' block. This then identifies the lightness of the resulting monotone block K'. The AC components are then scaled with linear constants per component. For some region around the converted K' the color conversions are linear. Linear operations in the real space can be moved to the transform space. For each AC position after scaling the nonzero coefficients are summed. The resulting K' block can be either JPEG compressed or go through the Inverse Discrete Cosine Transform (IDCT).

Figure 2 shows a plot of the scale factors for the color to gray conversion. The scale factors of cyan, magenta, yellow, and black at each black level were generated based on a cmyk to K' lookup table of size 17x17x17x17. The scale factors were obtained by solving overdetermined systems with a numerical algorithm such as Singular Value Decomposition (SVD). The scale factors of each color component then was analyzed against the levels of output color, and a mathematical model was derived. The equations for the fits are included on the graph. Our experiment showed that the scale factors for each color component can be fit with a polynomial over its entire range. The model is useful for smoothing the noisy data, predicting the missing data points, and creating abort criteria.

Each curve was fit with a polynomial. The X-axis is the output gray from 28 to about 240.

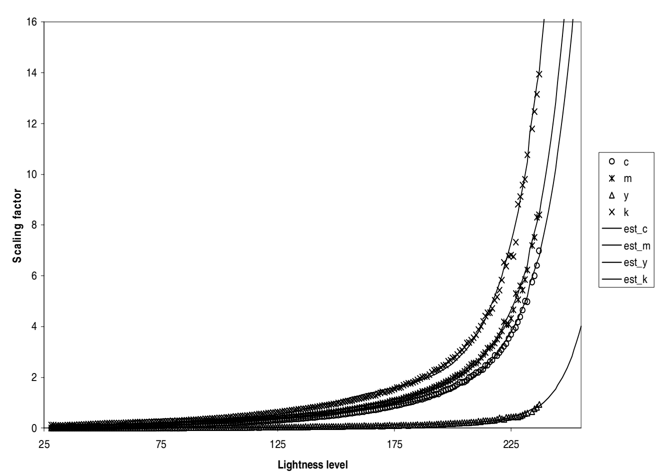

***Figure 2.** Scaling factors at each lightness level for cmyk to gray conversion*

Color to color conversion

For the color to color conversion, a Swop lookup table from CIELAB to CMYK with size of 33x33x33 was used. The same technique was used for generating the scale factors of L*, a*, and b* component at each cyan, magenta, yellow, and black level. These scale factors again were analyzed against each level of output components. The results are shown in Figures 3- 6.

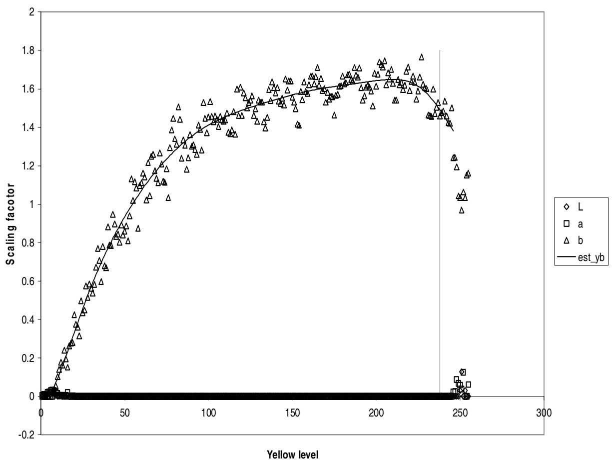

***Figure 3**. Scaling factors at each yellow level for CIELAB to cmyk conversion*

Figure 3 shows CIELAB constants vs. the output yellow component. It can be seen that the scale factors of L* component and a* are independent on yellow component. Only scale factors of b* component is the function of yellow. The results are consistent with color science concepts, since yellow is strong in b* component. The noisy data at the end of scale factors of L*, and a* indicate the abort level of yellow component.

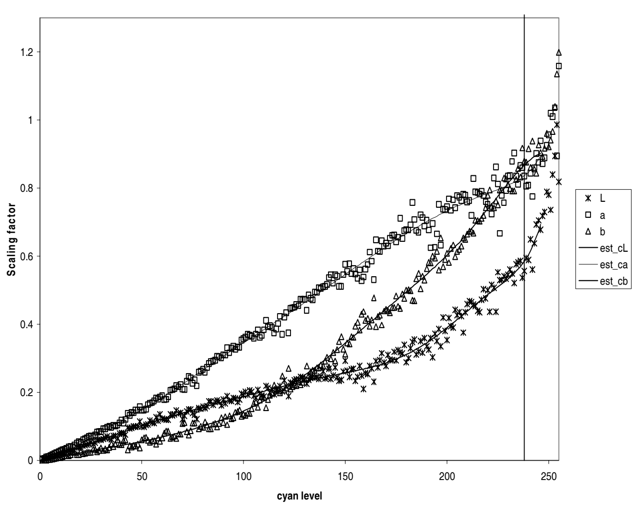

***Figure 4**. Scaling factors at each cyan level for CIELAB to cmyk conversion*

Figure 4 shows CIELAB constants vs. the output Cyan component. Cyan colors are light to medium colors located at the middle of third quadrant in CIELAB color space with strong –a* and –b* values. The results showed that the scale factors of all L*, a*, and b* component are the functions of cyan component, which is consistent with the nature of cyan colors. However, the function does not fit well at the end of cyan component. The abort level of cyan component is consistent with the yellow component.

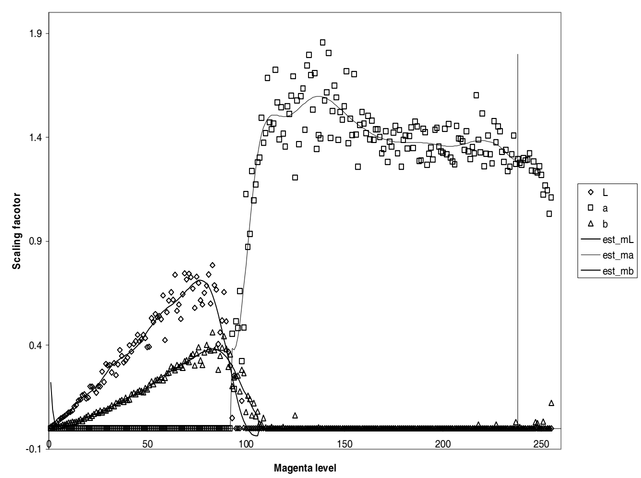

***Figure 5**. Scaling factors at each magenta level for CIELAB to cmyk conversion*

Figure 5 Shows the CIELAB constants vs. the output magenta component. The magenta colors located at the fourth quadrant of the CIELAB color space with +a* and –b* values. Like cyan toners, the lightness of magenta colors in general is from light to medium. The fitting was divided into two parts: before and after level 93. It's interesting to discover that for the magenta level below 93, only the scale factors of L* and b* are the function of magenta, and the scale factors of a* is independent of magenta. For the magenta level above 93, only the scale factors of a* is the function of magenta, and the scale factors of L* and b* are independent of magenta. We believe these results reflect the nature of this specific magenta toner. The results indicate that similar abort criteria were applied.

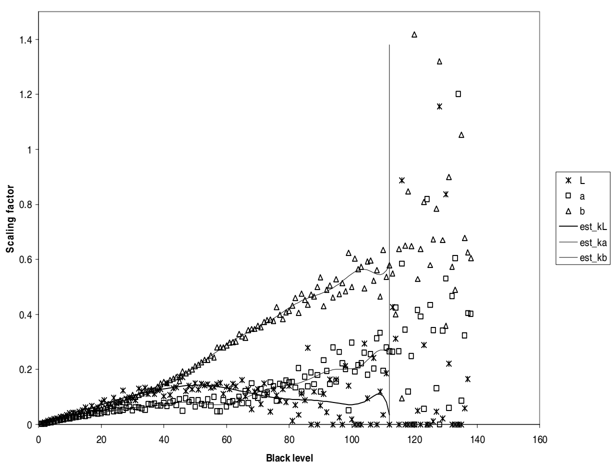

***Figure 6**. Scaling factors at each black level for CIELAB to cmyk conversion*

Figure 6 shows CIELAB constants vs. the output black component. The black levels in the CIELAB to CMYK were only up to 138 in the original Swop data. The data are relatively noisy because the black component is complimentary toner only used for adjusting colors of cyan, magenta, and yellow component. However, Models can be derived form the data, and abort criterion were applied based on the model fit.

Abort Criteria

A key piece of this technique is the ability to know when the error from the assumption of linear color conversions into grayscale is too large. The process then defaults back to the four IDCTs followed by nonlinear conversion in the real domain. Figure 2 shows that for the CMYK to monochrome gray conversion there is no need for an abort unless the rapid change in values for larger output grays is considered to introduce unacceptable errors. For an output that will ultimately be halftoned, the previous disclosure described experiments that demonstrated a large tolerance for AC errors in the halftoned output.

Figures 3 through 6 show a different story for the color conversions to another color. The input data is CIELAB, a device independent color space. The output colors are device dependent CMYK. The upright lines in the graphs are examples of the abort criteria. For output values less than the abort value, the color conversion is done in the DCT domain. For values at or greater than the vertical lines, the traditional color conversion in the real domain is used after doing the inverse transform on each input component.

Figure 6 shows near 100 on the horizontal axis another possible abort region. The constants are changing so rapidly that the designer could choose to use the traditional method in that region. Since the eye is not as sensitive to colors, the need for the second abort would depend upon the application and the amount of error that could be tolerated.

Conclusions

A novel technique has been developed for high speed color conversions for JPEG compressed images. The color conversion is processed in the transform domain instead of the traditional spatial domain. Abort criteria also have been developed to determine when the color conversion needs to be processed in the traditional spatial domain. Our experiments indicate that partial or whole color conversions can be processed in the transform domain.

References

[1] W.B. Pennebaker and J.L. Mitchell, JPEG: Still Image Data Compression Standard, Van Nostrand Reinhold:New York (c)1993.
[2] M.A. Wober and J. Lin, "Method And Apparatus For Processing A Color Map Using Discrete Cosine Transforms," U.S. Patent #5,533,173 issued July 2, 1996.

Author Biography

Yue Qiao is a color scientist/architect at Ricoh/IBM InfoPrint Solution Company, Boulder, CO. She received her master degrees in physics and imaging science from John Carroll University and Rochester Institute of Technology respectively. she has been working on numerous color science and print quality related projects including color management resource architecture development, color management systems, color halftoning, and image quality evaluations. She is currently finishing up her Ph.D in applied mathematics at Colorado State University.