Extraction of Non-Linear Components from 3D- & LUT In ICC Profiles and Re-composition of New Profile for Better Color Reproduction

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Abstract

Color conversion model used in ICC specification is based on multi-dimensional look-up table and linear interpolation. This color conversion model is useful for device independent color reproduction. But in order to get a high spaed of color conversion for large image data, this interpolation needs simple calculation process. If non-linear interpolation smoothness will become better than simple calculation method. We tried re-composition of 3D-LUT to bigger three dimensional lookup table by non-linear interpolation before image conversion by linear interpolation, and explain its process and evaluated results.

Introduction

To make a multi-dimensional lookup table for device independent color reproduction, we need tri-stimulus color value of sampled color of color device and its drive data. If color characteristics of device is non-linear, multi-dimensional lookup table need bigger table for accurate color conversion. And to get a large number of lookup table data, many color samples are needed to get whole lookup table data. Three dimensional lookup table has many entries and sometimes it will exceed color sample points. For example $4 \times 4 \times 4$ 3D-LUT tables have 4096 entries and 5x5x5 3D-LUT has 32768 entries. To make those large number of sample colors is not effective and some interpolation method is introduced to make bigger look-up tables from small lookup tables. In this interpolation, simple linear interpolation method is not valuable for 3D-LUT because its data does not reflect non-linearity of target device. In this interpolation process, interpolation with accounting the data of subsequent points will realize a smooth interpolation process and eliminate an interpolation trror. We tried to make bigger 3D-LUT from small 3D-LUT by spline interpolation.

ICC Color Conversion Model

Color Conversion Model

The ICC (International Color Consortium) introduced some color conversion model for specified devices. Table 1 shows those models for specified devices.

Table 1. ICC color conversion model

Device	Color conversion model
Input device	3-component TRC based N-component LUT based
Device device Output device	3-component TRC based N-component LUT based

The TRC based model is composed with 3×3 mauix and one dimensional lookup table(TRC), and its characteristics are almost decided by number of entries and data width of TRC. The LUT based model is composed with multi-dimensional lookup tables and components of TRC model. In LUT based model a size of LUT are defined but not interpolation method. Figure 1 shows functional biock in N-component LUT based model.

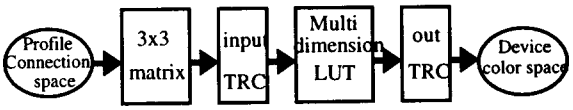


Figure 1. N-component LUT based color conversion model

If profile connection color space (PCS) is selected to XYZ, PCS is converted to RGB by 3×3 matrix and its output data is adjusted by input TRC. Multi-dimensional LUT convert adjusted RGB data to device color space. The output TRC adjust gamma characteristics for device gamma.

If this model is applied to the conversion from device color space (example:CMYK) to PCS, 3×3matrix is not used, and input TRC has 4 channels and multi-dimensional LUT has 4 channel input and 3 channel output, and output TRC has 4 channels.

Linear Interpolation

The multi-dimensional LUT is composed with small multi-dimensional LUT and multi-dimensional interpolator to reduce memories. The interpolation method is not decided in ICC and based on users selection what type of interpolation they use. In order to avoid interpolation error, bigger LUT or sophisticated non-linear interpolation method is useful. But to get first speed for color conversion, interpolation method shall be simple calculation. Al-

ready proposed interpolation method, for example CUBE, TETRADEDRON, PYRAMID, PRISM, SLANT-PRISM, DISPHENOID-TETRAHEDRON are all linear type interpolation method. Those type of interpolation has some orders, true linear, hi-linear and tri-liner interpolation order. CUBE is tri-linear, PYRAMID and PRISM and SLANT-PRISM are bi-linear, TEDRAHEDRON and DISPHENOID-TEDRAHEDRON are true linear. Those order of interpolation causes some interpolation difference between those types. But if bigger LUT is used, those difference will decrease and simple interpolation become acceptable.

Non-Linear Interpolation

Spline Interpolation

Cubic spline interpolation is useful for connecting discrete points with smooth line. This spline curve expressed with third order polynomial expression which have a continuity of 2nd differential coefficients at each connecting point. Figure 2 shows cubic spline curve composed from 6 discrete points compared from linear interpolation curve.

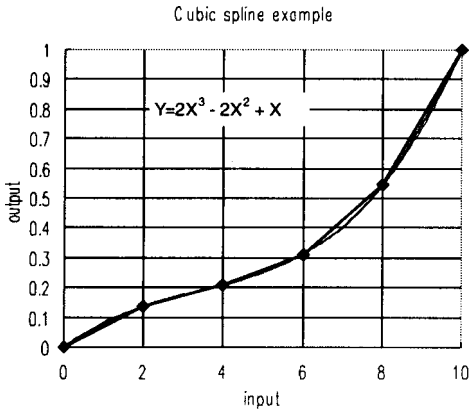


Figure 2. 3rd order spline interpolation for 3rd order polynomial function.

Multi-Dimensional Spline Interpolation

We expanded cubic spline interpolation to three dimension and applied to expand the size of 3D-LUT. Figure 3 shows the three step of interpolation. At step l, the cubic spline interpolation described is done along side line and interpolated data at black dotted point in Figure 3(a) is got on each side line. Next step 2, two directional cubic spline interpolation is done on each cubic surface plane. In this step two interpolation data are got from 2 interpolation line and mean value is used for interpolation value. At step 3, there are three interpolation lines and mean value of those interpolation values is used for final interpolated data at black points signed in step 3.

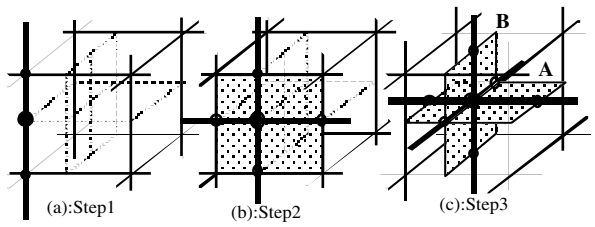


Figure 3. Three dimensional spline interpolation

ICC Profile Data Modification

3D-LUT Modification (RGB-CIELAB Conversion)

Instead of non-linear interpolation to all image data, a magnification of 3D-LUT by same non-linear interpolation method has same effect without excess calculation cost in image conversion process. Memory size is not critical problem when this conversion is done by computer software.

To estimate the accuracy of 3D-LUT magnification by cubic spline interpolation, we compared difference histogram of 3D-LUT for RGB-CIELAB conversion from that of linear type interpolation. Original 9cube LUT are expanded by 4 times larger by three dimensional cubic spline interpolation or PRISM interpolation or TETRAHEDRON interpolation. Figure 4, shows difference histogram of 3D-LUT data by spline interpolation or PRISM interpolation or TETRAHEDRON interpolation in RGB to CIELAB conversion table.

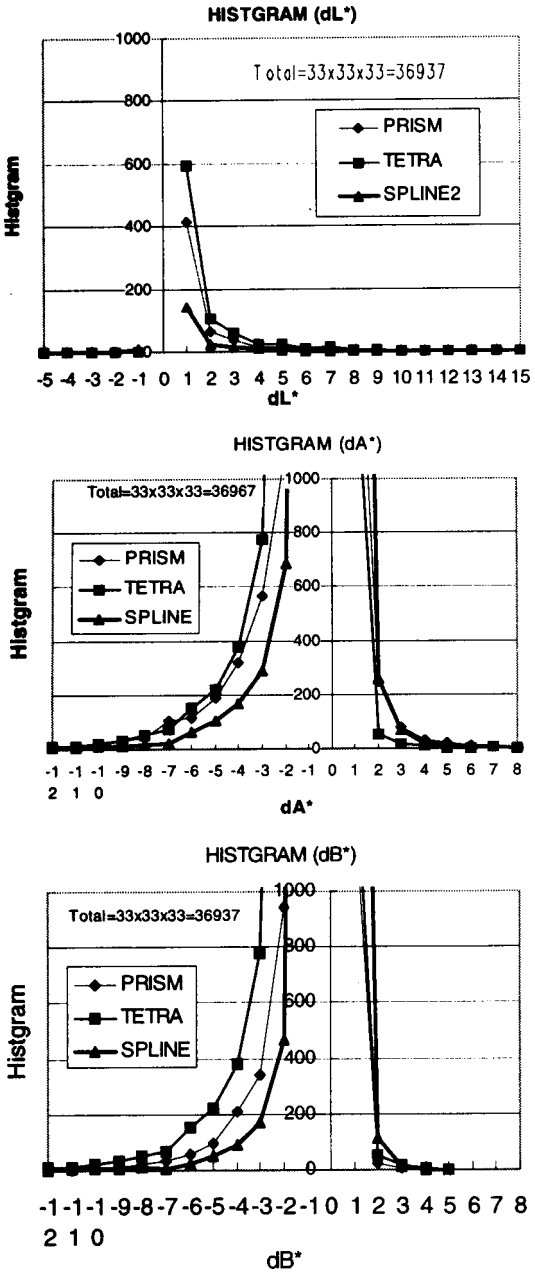
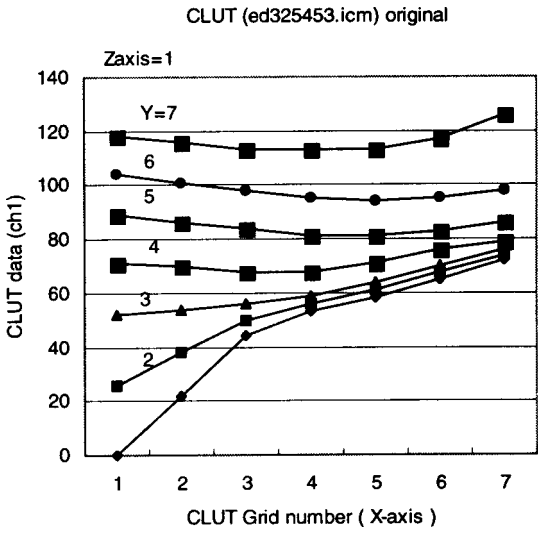
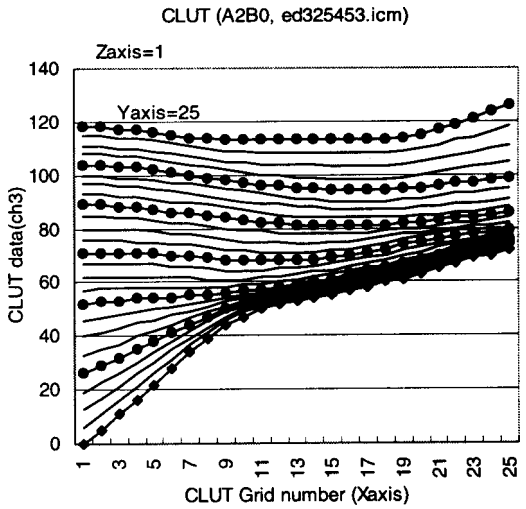


Figure 4. A distribution of 3D-LUT magnification error (dL, dA*, dB*) in different magnification method.*

Figure 4(a) shows histogram of numbers which has a difference of L* (dL*) in all 3D-LUT elements, and spline interpolation has small error compared from another two type. Figure 4(b) shows histogram in case for dA*. In positive dA* area spline method has large count compared from another linear interpolation method, but its value is small. In negative dA* area, error counts of spline interpolation become small. Figure 4(c) shows case for dB* and likely to the characteristic of dA*. Those figures show cubic spline interpolation has small interpolation error compared from linear interpolation.



(a) Original 7 cube 3D-LUT



(b) magnified 33 cube by cubic spline

Figure 5. Characteristics of 3D-LUT decided in A2B tag of ICC printer profile. (InkJet)

(Expand 3D-LUT of ICC profile)

We tried to magnify 3D-LUT table of existing ICC table. Figure 5(a) is an original 3D-LUT data composed by 7 grids on first plane in Z axis. Those data are extracted from ICC profile of ink-jet printer. Figure 5(b) is an expanded LUT data by means of three dimensional cubic spline interpolation method. The grid of expanded 3D-LUT has 4 times larger than original 3D-LUT data. These pre- processing for 3D-LUT by non-linear interpolation is same effect to non-linear interpolation with 7 grids course 3D-LUT.

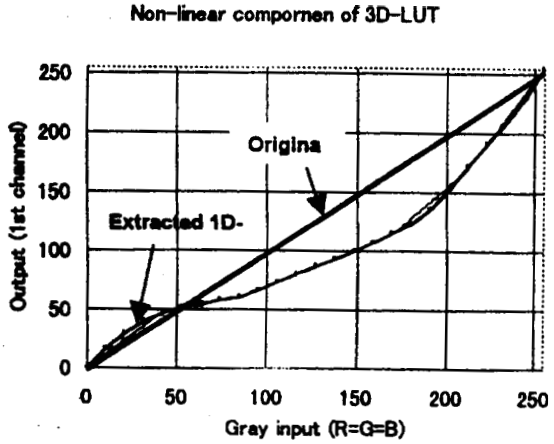


Figure 6. Characteristics of extracted ID component from 30-LUT(InkJet)

1D-LUT Modification

After extract 3D-LUT from ICC profile and magnify its grids and get bigger sized 3D-LUT by multi-dimensional cubic spline method, we extracted non-linear component from 3D-LUT to get better 3D-LUT data. Figure 6 shows original ID-LUT and extracted one dimensional component from 3D-LUT before and after magnification of 3D-LUT. This shows 3D-LUT has still one dimensional non-linear components that can be moved to input or output 1D-LUT. And characteristics of extracted ID-LUT after magnification of 3D-LUT is more smooth than without magnification.

Conclusion

In order to get high speed color conversion by multi- dimensional lookup table method, simple linear interpolation is used in color conversion engine. But this simplicity causes interpolation error. If high order interpolation or non-linear interpolation is applied to this method ,conversion error will reduce. In stead of image data calculation, the expansion of 3D-LUT by same non-linear interpolation is same effect. We introduced cubic spline interpolation to expand small 3D-LUT and extraction of one-dimensional component from 3D-LUT. This method can recompose ICC profile and get a better color conversion profile.

References

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3. Teruo Fumoto, SLANT/PRISM Convertible Structured Color Processor MN5515, *Proceedings of the IS&T/SID 1995 CIC*, 101-105.

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