Color space conversion algorithm and comparison study

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Abstract. Purpose The advantages and disadvantages between various conversion algorithms are analyzed, and the relatively optimal conversion algorithm is obtained by comparing color difference, conversion accuracy, and operability. Method Using 729 sets of data from the K=0% part of the ECI2002 standard color target as samples, experiment 2° was conducted under the D50 light source in the field of view, and the minimum, average, and maximum color differences of C, M, and Y were analyzed and compared by three unused color space conversion algorithms, and the operability of the three algorithms was also analyzed. Phenomenon Of the three algorithms, the polynomial regression algorithm and the neural network algorithm have similar errors, while the Nünchberg equation is less accurate and has a larger error. The operability of each of the three algorithms has advantages and disadvantages. Conclusion The polynomial regression algorithm has the highest accuracy, the lowest error, and the best method.

Keywords: color space, conversion, RGB, CMYK, CIEXYZ, L*a*b*.

1. Introduction
The study of color space conversion models is one of the key techniques to ensure the accurate conversion of colors between different imaging devices. At present, the commonly used color space conversion methods include plane theory, Newcomb equation method, table look-up interpolation, polynomial regression method, and neural network. This paper provides a categorical review of the literature on color space conversion.

2. Color space
Color space has long been widely used in our life and work, the following will introduce some of the current common color space, see Table 1.

| Color Space | Relevance to equipment | Applications | Meaning |
|-------------|------------------------|--------------|---------|
| RGB         | Related                | TV, CRT monitors for computers | R, G, B represent the 3 primary colors of red, green and blue respectively |
| CMYK        | Related                | Printing Industry | C, M, Y, K represents the four colors of printing: cyan, magenta, yellow, black |
| HSV         | Related                | Computer monitors | H : Hue, S : Saturation, V : Brightness |
| YUV         | Related                | TV, image transmission | Y: Brightness, U, V: Chromaticity |

Table 1. Commonly used color spaces
YCrCb | Related | TV, image transmission
---|---|---
The offset version of YUV. y: luminance, Cr: the difference between the red part of RGB input signal and the luminance value of RGB signal. cb: the difference between the blue part of RGB input signal and the luminance value of RGB signal.

L*a*b* | Unrelated | Mainly as the "intermediary space" for the transformation of each color space
---|---|---
L: luminance, a, b: color opposing dimensions

CIEXYZ | Unrelated | Developed from RGB space, correcting the problems associated with RGB space
---|---|---
X, Y, Z are converted from the three stimulus values of the spectrum respectively

LUV | Unrelated | A kind of uniform color space
---|---|---
L: Brightness, U, V: Chromaticity

3. Empirical research on color space conversion algorithm

3.1. Neugebauer equation
In the 1930s, Neugebauer derived a mathematical model for the color presentation of printing dots based on the printing dot model and Grassmann's color mixing law, i.e., the Nünchberg equation. According to the principle of dot color presentation, the ratio of the eight basic color lights produced by overprinting can be deduced from the dot area rate of each color ink at a certain place of the print, and then the X, Y and Z stimulus values of the eight color lights after mixing can be calculated according to Glassman's color mixing law. The model establishes the conversion relationship between CIEXYZ color space and CMYK color space from the perspective of color science, and gives the quantitative description between the mixed color tri-stimulus value and the dot area rate of each color ink from the mathematical perspective, which has important theoretical and practical values.

Marc Mahy (1997) [1] proposed an analytical method for calculating the color gamut of a "well-behaved" process based on the Neugebauer model.
Liu, H. X., Yuan, Y. X., and Yang, W. J. (1999) [2] Improvement of the accuracy of the calculation of the Nünchberg equation using the dot-expansion correction method.
Zhu, M., Liu, Z., and Chen, G. X. (2011) [3] introduced a color gamut compression scheme based on node addresses during the inverse solution of the partitioned Nünchberg system of equations using an iterative method, and successfully solved the outlier problem arising from the color separation solution for sample points outside the target color gamut.

3.2. Polynomial regression algorithm
Polynomial regression algorithm is an assumption based on a kind of source color space and target color space can be linked by a set of equations that hold simultaneously. The sample color descriptions are selected in the known source color space target color space and modeled by the selected polynomials to obtain the coefficient matrix of the polynomials. The source color space color descriptions are then transformed to the target color space by solving the resulting coefficient matrix. The only condition of the polynomial regression algorithm is that the number of sample points in the source color space should be greater than the number of terms of the selected polynomial. The coefficients in the polynomial are solved and substituted into the data in the source color space, and the result of the conversion can be derived from the equation.

Yanfang Xu and Wenyao Liu (2004) [4] proposed a method for color printer color space transformation. Based on the one-dimensional and three-dimensional feature relationship between the output color monochromatic chromaticity characteristics and the digital drive values and the complex color and monochromatic chromaticity characteristics, this feature relationship is quantified by the
concept of chromaticity density and the neural network method, and the transformation relationship between the output chromaticity color space and the input digital color space is established.

Lee, Archibald (2008) [5] proposed an innovative and robust algorithm for color space conversion and color metric distribution system evaluation, using a three-dimensional polynomial to convert three-dimensional RGB values into a simple one-dimensional color space, establishing a conversion between RGB and HIS spaces.

Cao, Congjun, Zhou, Mingquan, and Kang, Yi (2008) [6] established a CMYK to L*a*b* conversion model by using the binary linear regression method of mathematical statistics, and the CMYK to L*a*b* conversion model was established by fitting the coefficients of each four-color plane equation by least squares and numerical analysis.

HuiFang Yang, YaoHua Yi, JuHua Liu, XiaoYing Wang (2015) [7] established a set of three-color printing color separation models based on polynomial regression algorithm for multicolor separation. After the color space is divided and subdivided into several cells, a polynomial regression model is developed for each cell.

3.3. Neural network algorithm
With the development of computer technology, some new techniques are used to solve highly nonlinear relationships and simulate human decision-making processes in practical studies, such as expert systems, neural networks, artificial intelligence, and fuzzy logic techniques. In recent years, neural networks and fuzzy logic techniques have been applied to the problems of modulation and color space conversion of colored inks.

Maozu Guo, Yadong Wang, Xiaohong Su, and Xingqi Wang (2000) [8] proposed a BP network-based color matching method to establish a conversion model from RGB color space to CMYK color space.

Cao Conjun (2008) [9] introduced GRNN into the study of color conversion for the first time on the basis of plane theory, and modeled the sample data grouped and ungrouped according to L*, respectively, and the generalized regression neural network has advantages over BP neural network in terms of training simplicity, training speed and accuracy.

Ji-Chuan, Zhou-Sheng, Shi-Yi (2009) [10] based on the fuzziness of color, based on the basic theory of fuzzy control, used triangular affiliation function and established fuzzy rules by experiment to realize the conversion from RGB to L*a*b* color space model.

Ji-Chuan, Guo Ling-Hua, Zhang Mei-Yun, and Shi Yi (2010) [11] dynamically divided the RGB color space into several subspaces according to the requested color values, and used BP neural networks in the subspaces for color space conversion. This method effectively avoids the local optimum phenomenon of the neural model in the whole color space, thus greatly improving the accuracy of the color space conversion.

Jing Zhang (2015) [12] improved the BP neural network using a strong predictor combined with the thinking evolution method. The method effectively improves color recovery accuracy while reducing the number of experiments.

4. Contrast Analysis

4.1. Color difference comparison
Using 729 sets of data from the K=0% part of the ECI2002 standard color target as samples, the experiments were conducted under 2°fields of view and D50 light sources, and the minimum color difference (%), average color difference (%), and maximum color difference (%) of C, M, and Y were analyzed, respectively, as shown in Table 2.

Table 2. Comparison of color difference between the three methods.

| Conversion method | Color Block | Minimum color difference [%] | Maximum color difference [%] | Average color difference [%] |
|-------------------|-------------|------------------------------|-----------------------------|------------------------------|
| Neugebauer        | C           | 0.180                        | 19.477                      | 4.848                        |
According to the analysis of Table 2, which reflects that the polynomial regression algorithm and the neural network algorithm have similar errors, while the Nünchberg equation has the worst accuracy and the largest error; the polynomial regression algorithm has the highest accuracy.

### 4.2. Operability comparison

The Nürnberg equation method requires only a few measurements to establish the conversion relationship. However, it does not take into account the actual printing process of cyan, magenta, yellow ink color gamut and ink printed on paper and other factors such as the impact of the phenomenon of light penetration and thus the accuracy is not high, on the basis of the development of the modified Nusukeborg equation, although the impact of the above factors, but color printing color is affected by many reproduction conditions, which makes the generation of color and each color element between the function of the relationship is not determined, only the existence of Only the correlation, and the correction coefficient of the modified Nürnberg equation is difficult to confirm, generally using empirical values, this empirical value to determine the more difficult. The lattice-like Nünchberg equation has higher accuracy than the first two algorithms, but the solution process is complicated and the conversion error is not ideal.

The polynomial regression algorithm is an ideal method for linear space conversion. Its inverse conversion model is easy to establish, sample points are chosen arbitrarily, no segmentation is required, the algorithm is simple to implement and runs fast. However, for nonlinear color space conversion, it cannot guarantee the same conversion accuracy over the whole color gamut, and too high number of terms will lead to oscillation.

The neural network method has nonlinear mapping capability, can iterate to reduce the error, and has high accuracy. However, the convergence speed is slow. There are local minima in the objective function. Need to train the modeled data in segments, and the number of implied layers and neuron units are difficult to determine.

In summary, the operability of each of the three algorithms has advantages and disadvantages, but the polynomial regression algorithm has the highest accuracy and therefore the polynomial regression algorithm has better conversion.

### 5. Summary

The study of color space conversion models is one of the key techniques to ensure accurate color conversion between different imaging devices. This paper provides an in-depth study of the main references and related techniques in this field, as well as an error comparison and operability analysis of three of these algorithms. The results of this paper can be used to address high-fidelity color reproduction for color printing as well as isochromatic techniques.

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