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A comparative study on the difference of color space conversion based on table look-up method and neural network

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Objective To study the conversion model of RGB color space to CIE1976 $L^*a^*b^*$ color space with higher accuracy, which provides some value for the fields of computer color matching, color detection, and color reproduction. **Methods** The method of three-dimensional look-up table method and back propagation (BP) neural network are proposed, and the effect of the model built under the two methods is evaluated under the calculation of CIE1976 $L^*a^*b^*$ and CIE2000 color difference by NCS color card data. **Results** Under the calculation of CIE1976 $L^*a^*b^*$ color difference, the average color difference under the four interpolation methods of the three-dimensional look-up table is within 3, and the average color difference of the BP neural network algorithm is 1.8720. Under the calculation of CIE2000 color difference, the average color difference of the four interpolation methods of the three-dimensional look-up table drops within 1, and the average color difference of the BP neural network also shows a downward trend, and the specific value is 1.3449. **Conclusions** According to the result obtained by the research method, the color difference of the tetrahedral interpolation method is the smallest among the four interpolation methods of the three-dimensional look-up table method under both color difference formulas. Whether it is the three-dimensional look-up table method or the BP neural network, the model obtained by the CIE2000 color difference formula is the best. In general, for the two methods, the BP neural network method is more convenient and faster, and the color difference effect is also desirable.

Keywords: three-dimensional look-up table method, BP neural network, color space conversion, RGB color space, CIE1976 $L^*a^*b^*$ color space.

1. Introduction

Color space conversion is an important part of color management, where the key trick is to realize the conversion of different color spaces and obtain the corresponding results [1]. Color space conversion is very widely used in computer color matching, color reproduction, video capture display systems, *etc*.

The color space conversion mainly uses the color mixture model method, polynomial regression method, three-dimensional (3D) look-up table (LUT) interpolation method, and neural network model method [2]. The color space conversion method is also favored by many scholars. KANAMORI *et al*. [3] used uniformly spaced color data to build look-up tables from which colors were obtained directly or calculated using the interpolation method. Since the look-up table method has shown many advantages when applied to devices such as scanners and printers, XU [4] used the method for monitors to build a color space conversion model, and the color difference of the model was all lower than 3. As the CIE1976 $L^*a^*b^*$ color space is an irregular color space, a uniform reverse look-up table cannot be built by a uniform set of samples, ZHAO and LIU [5] proposed an interpolation algorithm based on cubic inversion to achieve the inverse variation of color values.

BOLDRIN and SCHETTINI [6] proposed the application of neural networks to the color matching problem. Because the 3D look-up table method tends to form a large color difference for the colors at the boundary of the color gamut, XU *et al*. [7] proposed a neural network method based on the masking equation and the concept of chromatic density. To prevent back propagation (BP) neural network training from falling into local error minima, ZHAO [8] established $L^*a^*b^*$ color space to CMYK color space conversion models based on BP neural network and GA-BP neural network. ZHANG [9] studied the algorithmic characteristics of RBF (radial basis function) neural network and applied RBF neural network to the color space conversion field, but there are still some problems. LI *et al*. [10] used T-S fuzzy neural network algorithm to build a model from RGB space to $L^*a^*b^*$ space. MACDONALD [11] used color space conversion of neural network to test various network structures with 8714 sets of real reflectance spectra, and the results showed that the error was less than 1 for more than 85% of the tested samples. SARAVANAN *et al*. [12] performed a real-time implementation of various color space conversion models and summarized their resource utilization and required power. YANG *et al*. [13] proposed an improved regularized limit learning machine algorithm to achieve fast and flexible conversion from $L^*a^*b^*$ to CMYK color space.

At present, the research methods for color space conversion are mature, but the accuracy of the models built by different methods still needs to be improved. The conversion of RGB color space to CIE1976 $L^*a^*b^*$ color space is implemented by the 3D look-up table method and BP neural network, and the color difference is calculated using CIE1976 $L^*a^*b^*$ and CIE2000. The purpose of this paper is to compare the effectiveness of the color conversion models constructed by the two methods and to complete a comparative analysis of the differences between the color space conversions processes of the methods used.

2. Theoretical approach analysis

There are two kinds of color space conversion methods: analytical model method, and empirical model method. The analytical model method establishes the conversion relationship through theoretical analysis, which has a certain theoretical basis; the empirical model method establishes the conversion relationship by measuring a large number of feature samples with certain mathematical methods, which is divided into the look-up table method, the neural network method, and so on. The method adopted in this paper belongs to the empirical model method.

2.1. Three-dimensional look-up table method

The 3D look-up table method is one of the most common methods used in color space conversion. The steps of the 3D look-up table method are divided into segmentation, extraction, and interpolation [14]. The interpolation methods used in the 3D look-up table method are trilinear interpolation, pyramidal interpolation, trigonal interpolation, and tetrahedral interpolation. In order to explore the methods to achieve a high-precision color space conversion model, the four interpolation methods will be tested separately in this paper to analyze and compare the optimal model.

The trilinear interpolation method requires 8 vertices to be used in the interpolation calculation, which requires 7 times linear interpolation and 3 times interpolation points for each calculation, making the calculation complex and inefficient. The difference between the four interpolation methods is the partitioning of the cube into different shaped geometries. The geometry vertex positions are then determined from the test points and calculated using the corresponding interpolation formulas. Figure 1 shows the 3D geometry of the cuts for each interpolation method.

The main implementation of this method is to select a test point in the test set, determine which geometry it is in according to the RGB values of the point, then find the RGB values and $L^*a^*b^*$ values of the vertex of the geometry, and calculate the $L^*a^*b^*$ values of the test point according to the vertex value of the geometry by different interpolation methods.

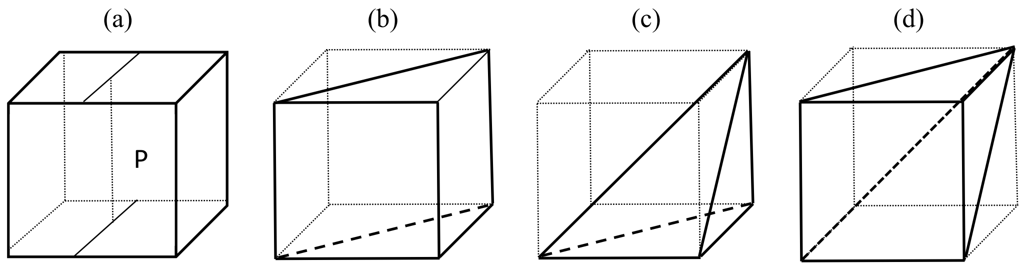

Fig. 1. Three-dimensional view of the geometry for each interpolation method. (a) Trilinear interpolation method, (b) trigonometric interpolation method, (c) tetrahedral interpolation method, and (d) pyramid interpolation method.

2.2. BP neural network method

Neural network technology has been gradually applied in various fields, which consists of multiple simple structured and interconnected processors, each of which can be regarded as a neuron to simulate the biological signal transmission between neurons with the information transfer between processors [15]. The neural network takes the color values of the color samples in the sample space as the original data, and then the mapping relationship between the original space and the target space is obtained through network training and testing to establish a model that satisfies the color space transformation.

The BP neural network is one of the more widely used neural networks, which is a multilayer forward network with unidirectional propagation and is an essentially gradient descent method [16]. The BP neural network includes the basic structure of input layer, implicit layer, and output layer, as shown in Fig. 2. The input signal is propagated forward to the implicit layer after the activation function, and then the output information from the implicit layer is passed to the output layer, and finally the result is output. The number of layers and nodes of the hidden layer varies from case to case, and after comparing the training results, we can get a more suitable number of layers and nodes of the hidden layer.

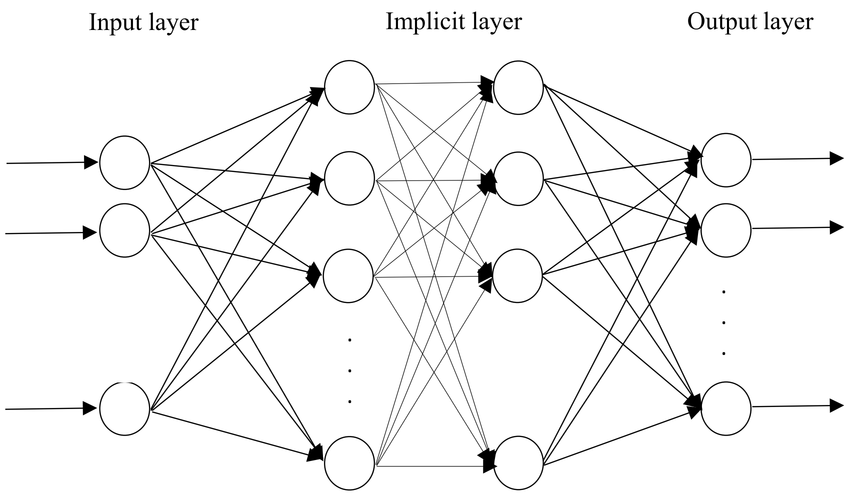

Fig. 2. BP neural network structure diagram.

3. Software simulation

3.1. Data sources

The full name of NCS is Natural Color System. Its color sample system contains 1953 standard color samples, covering the entire color space (see Fig. 3). The NCS color standard is being developed as a nationally relevant standard, mainly including Swe-

Fig. 3. NCS color card.

den, Norway, Spain, and other countries, and is being widely adopted worldwide as an international common color standard [17]. The data for this paper were obtained from the Swedish NCS color standard color book in the Color Tell color book query on the color management website. All the data in the color book were randomly selected, and 1000 of the NCS color card swatches were chosen as the data for the model.

3.2. Color space conversion using 3D look-up table method

In this paper, the programming environment used for the 3D look-up table method is VC++6.0. For the sake of fast and convenient calculation, the grading method is chosen as a five-level partition, and the partition nodes used for R, G, and B are: 0, 64, 128,

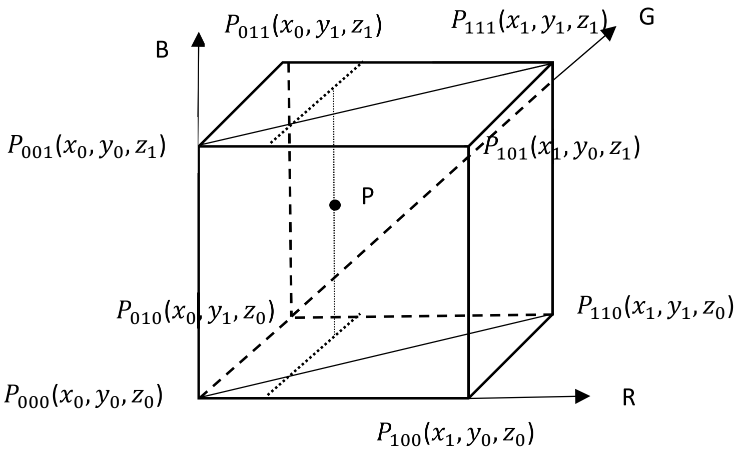

Fig. 4. Cube structure diagram for 3D interpolation.

192, and 255. Construct a look-up table using the RGB values of all sample points and the CIE1976 L*a*b* values. If the value to be found happens to be a raster point, the corresponding mapping value is found directly; otherwise, the mapping value is calculated by interpolation. Different interpolation methods have their own corresponding interpolation formulas [18]. The cube of the 3D interpolation is shown in Fig. 4. The vertices of x_i, y_i and z_i correspond to the R, G, and B values of the cube, respectively. And for the simplicity of each interpolation formula, each vertex is labeled as $P_{000} \sim P_{111}$, and P is the point to be found.

The 3D look-up table method uses five levels of partitioning to establish the conversion relationship; 1000 NCS color samples are used to test the model accuracy, and the color differences under four interpolation methods are counted, using CIE1976 L*a*b* and CIE2000 color difference calculation formulas. The color difference formula of CIE1976 L*a*b* is:

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2} \tag{1}$$

CIE2000 color difference calculation relative to CIE1976 L*a*b* color difference calculation in the algorithm has been improved, and the color difference calculation value and the human eye assessment are closer, and the color difference formula is:

$$\Delta E = \sqrt{\left(\frac{\Delta L}{K_L S_L}\right)^2 + \left(\frac{\Delta C}{K_C S_C}\right)^2 + \left(\frac{\Delta H}{K_H S_H}\right)^2 + R_T\left(\frac{\Delta C}{K_C S_C}\right)\left(\frac{\Delta H}{K_H S_H}\right)} \tag{2}$$

In order to be more intuitive and easily to observe, the overall interface design of the 3D look-up table method was carried out, and the main interface implemented is shown in Fig. 5.

The color difference statistics interface of each interpolation method under the CIE1976 L*a*b* color difference formula is shown in Fig. 6.

Through the color difference statistics chart, the data are presented in Table 1.

It can be seen from the data that the average color difference of the four interpolation methods is all within 3, which is within the range of human visual insensitivity. It has better achieved the modelling conversion from RGB to CIE1976 L*a*b* space, and obtained the spatial distribution of color difference. However, it can be seen the color difference obtained by the pyramid interpolation method is significantly larger than other interpolation methods, and the conversion accuracy of this method needs

Table 1. Color difference statistics under CIE1976 L*a*b* calculations.

Interpolation method	Minimum color difference	Maximum color difference	Mean color difference	The proportion of $\Delta E \leq 3$
Tetrahedral	0	7.2468	2.0265	76.6
Trilinear	0	7.6914	2.3207	74.1
Trigonometric	0	7.2468	2.1718	75.2
Pyramid	0	14.9493	2.9806	65.5

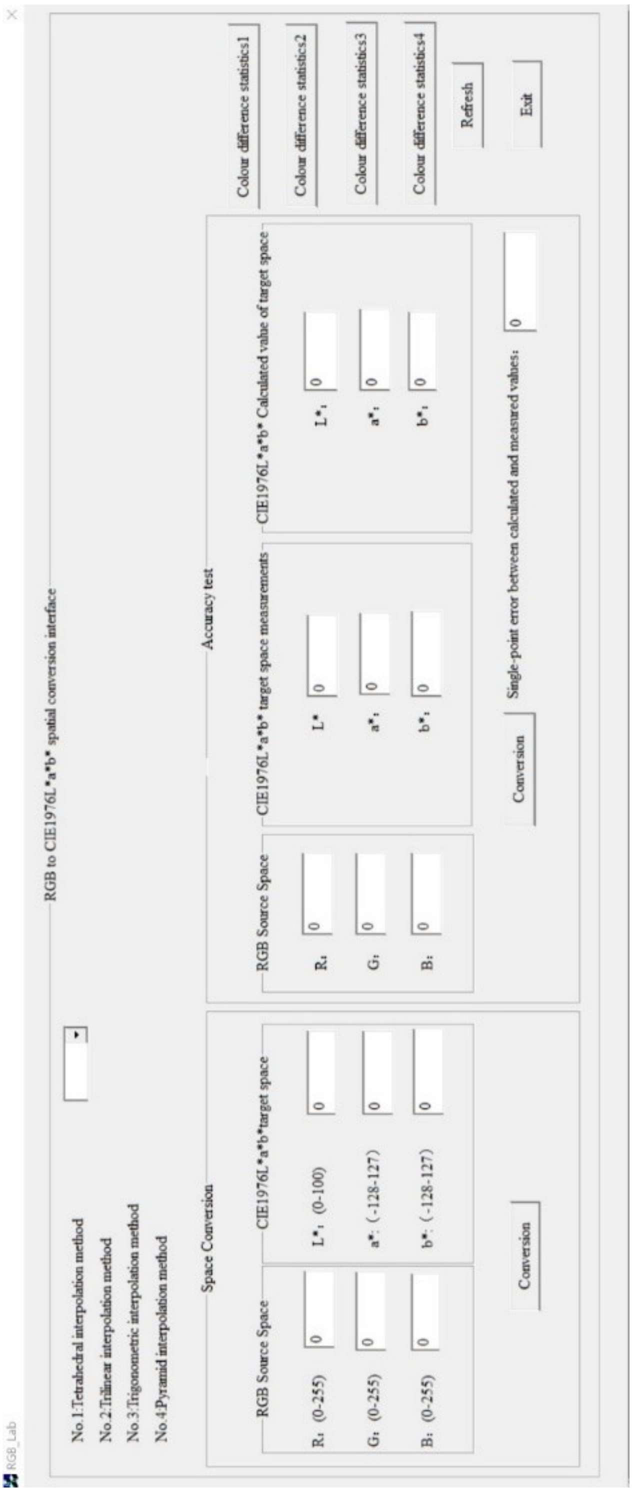

Fig. 5. The RGB to CIE1976 $L^*a^*b^*$ spatial conversion interface diagram.

Fig. 6. Color difference statistics for each interpolation method under CIE1976 $L^*a^*b^*$ calculation. (a) Tetrahedral interpolation method, (b) trilinear interpolation method, (c) trigonometric interpolation method, and (d) pyramid interpolation method.

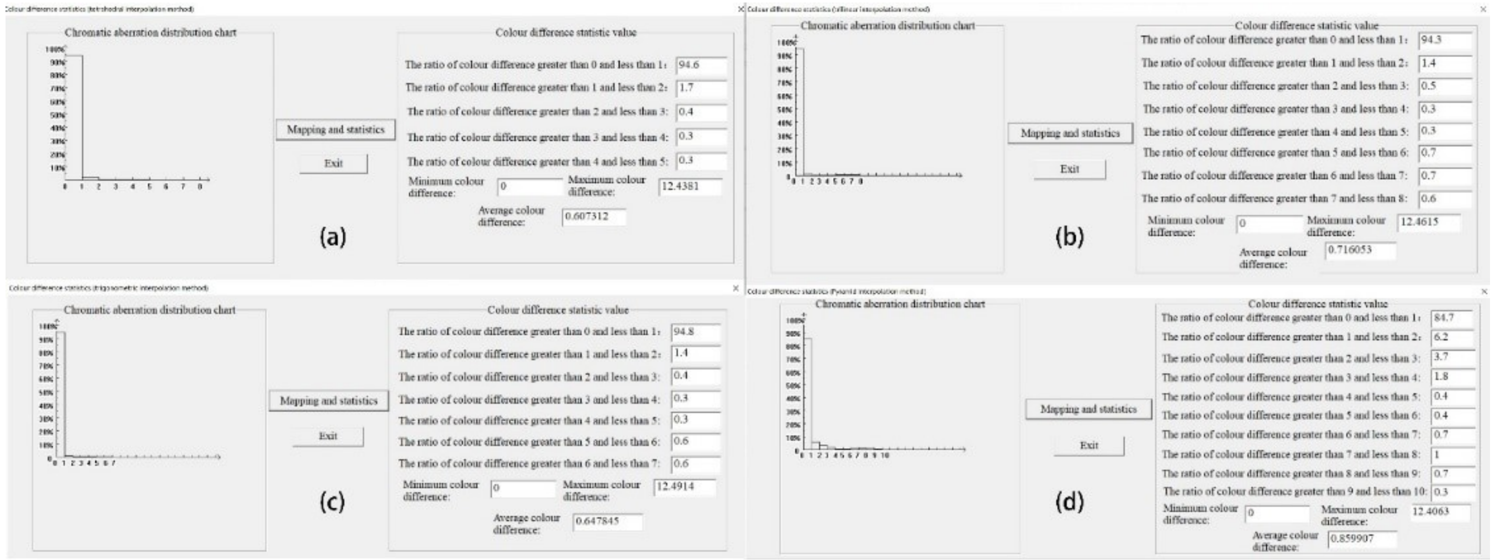

Fig. 7. Color difference statistics for each interpolation method under CIE2000 calculation. (a) Tetrahedral interpolation method, (b) trilinear interpolation method, (c) trigonometric interpolation method, and (d) pyramid interpolation method.

Table 2. Color difference statistics under CIE2000 calculations.

Interpolation method	Minimum color difference	Maximum color difference	Mean color difference	The proportion of $\Delta E \leq 3$
Tetrahedral	0	12.4381	0.6073	96.7
Trilinear	0	12.4615	0.7161	96.2
Trigonometric	0	12.4914	0.6478	96.6
Pyramid	0	12.4063	0.8599	94.6

to be improved. Since the selected segmentation sampling point is single, the overall modeling effect may be further improved by changing the segmentation point.

The color difference statistics interface under the CIE2000 color difference formula for each interpolation method is shown in Fig. 7.

Through the color difference statistics chart, the data are presented in Table 2.

It can be seen from the data that the average color difference of the established models is within 1, which is smaller than the error calculated by using the CIE1976 $L^*a^*b^*$ color difference formula, and the proportion of $\Delta E \leq 3$ which is more than 90%, which is due to the existence of K_L, K_C and K_H three correction parameters in the color difference formula of CIE2000, which can achieve better results by adjusting their values according to the actual.

3.3. Study of color space conversion using BP neural network

In this paper, the BP neural network method is simulated and analyzed by MATLAB software, 1000 NCS data are used as a test set to check the goodness of the network structure. The color difference effect obtained from the model training is relatively good when the network structure is chosen as 3-15-15-3 by changing the network structure. Other parameters of the neural network are set: activation function is tansig and purelin, training function is trainlm, maximum training number is 2000, learning rate is 0.1, and the minimum error of the training target is 0.001.

When the CIE1976 $L^*a^*b^*$ color difference formula is selected, the error 3D plot of CIE1976 $L^*a^*b^*$ values in the target space is shown in Fig. 8, and the average color difference of the model is calculated to be 1.8720, the minimum color difference is 0.1128, and the maximum color difference is 9.4947.

The network performance plot of the BP neural network shows the linear relationship between the number of iterations and the mean square error (MSE), which refers to the expected value of the squared difference between the parameter estimate and the true value of the parameter, using the covariates of the true and calculated values of L*, a* and b*. The specific formula is:

$$\mathrm{MSE} = \frac{1}{1000}\sum_{i=1}^{1000}\frac{(L^*_{i\,\mathrm{true}} - L^*_{i\,\mathrm{calc}})^2 + (a^*_{i\,\mathrm{true}} - a^*_{i\,\mathrm{calc}})^2 + (b^*_{i\,\mathrm{true}} - b^*_{i\,\mathrm{calc}})^2}{3} \tag{3}$$

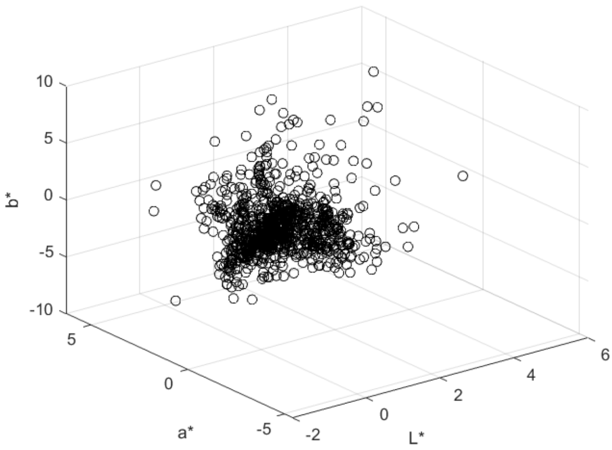

Fig. 8. Three-dimensional view of the error in the target space.

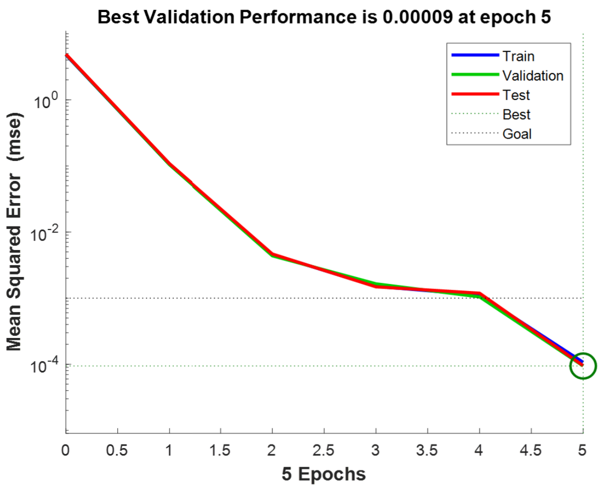

Fig. 9. BP neural network performance graph.

The network performance is plotted in Fig. 9, from which it can be seen that the mean square error of training is about 0.0001 when the number of iterations is 5, which fully achieves the training target of 0.001.

The graph of the correlation analysis results for this network is shown in Fig. 10. From the figure, it can be seen that the network achieves a correlation of 0.99 or more in both the training and test sets, characterizing that the network structure is very well trained and proving that the proposed model works well.

When the CIE2000 color difference formula is chosen, the network structure remains unchanged, and the average color difference is 1.3449, the minimum color difference is 0.0881, and the maximum color difference is 7.0970. Compared with the

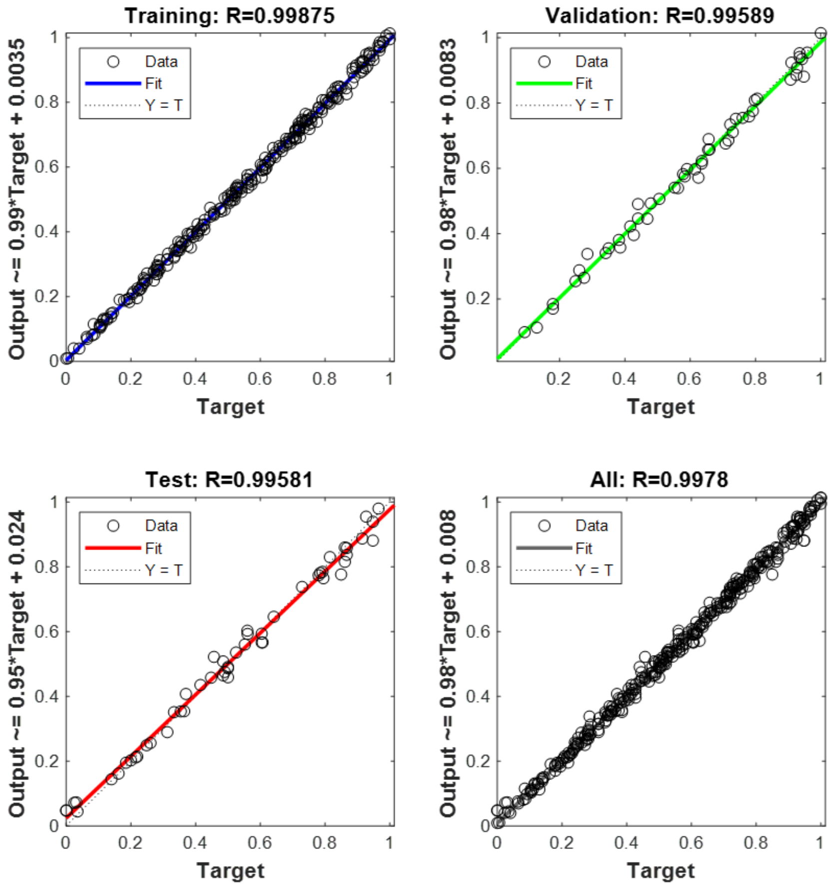

Fig. 10. Correlation analysis diagram of BP neural network structure.

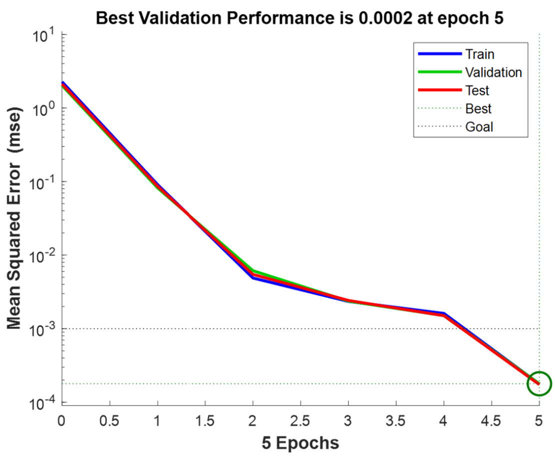

Fig. 11. Neural network performance graph.

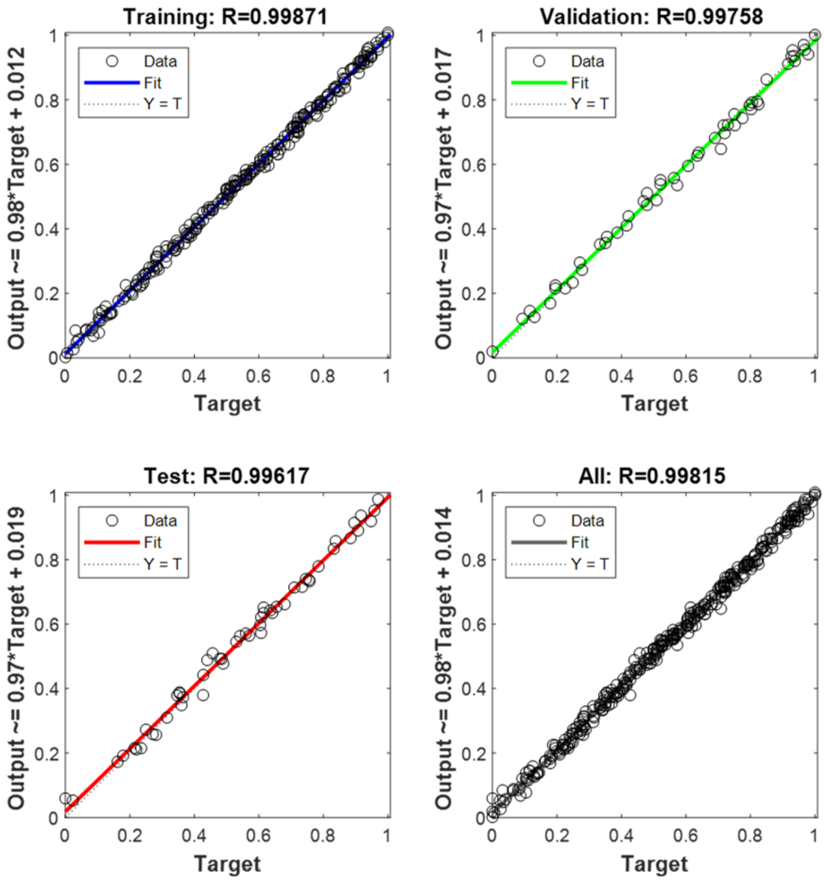

Fig. 12. Correlation analysis diagram of neural network structure.

CIE1976 $L^*a^*b^*$ color difference formula, the model accuracy has been greatly improved and the results are better. The network performance is plotted in Fig. 11, from which it can be seen that the mean square error of training is 0.0002 when the number of iterations is 5, which fully achieves the training target of 0.001.

The graph of the correlation analysis results of this network is shown in Fig. 12. As can be seen from the figure, the correlation of this network structure is still very strong, and the correlation of the network model as whole does not go to change with the change of the color difference formula.

4. Conclusion

In this paper, the modeling transformation of RGB to CIE1976 $L^*a^*b^*$ space is established by two methods, namely, the 3D look-up table and the BP neural network method, which are implemented by VC++6.0 and MATLAB software, respectively, and the established models are effective. Among them, the color difference of the tetrahedral interpolation method in the 3D look-up table method is the smallest, and the model established is the best. In the BP neural network, the model built based on the CIE2000 color difference calculation formula performs better with average color difference of 1.3449.

By comparing the two methods of 3D look-up table and BP neural network, BP neural network modeling is faster and close to 1 under both color difference calculation methods, and its operability is better. Since the 3D look-up table method involves uniform grading of the original space, different grading methods may also affect the final error effect of the model, so the modeling of other grading methods remains to be studied. For BP neural networks, the network structure is very important, especially the number of nodes in the hidden layer, so finding the network model under other node conditions also needs more study. Overall, the proposed color space conversion model method provides some reference value for the fields of computer color matching and color reproduction.

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Disclosures
The authors declare no conflicts of interest.

References

[1] BAO X., SONG W., LIU S., *Research on color space conversion model from CMYK to CIE-LAB based on GRNN*, [In] Paul M., Hitoshi C., Huang Q. [Eds.], *Image and Video Technology. PSIVT 2017*, Lecture Notes in Computer Science, Vol. 10749, Springer, Cham. https://doi.org/10.1007/978-3-319-75786-5_21

[2] HAN X.J., SHI J.S., HUANG X.Q., *A study of multiple regression models for color printer characterization*, Optical Technology **37**(1), 2011: 25-30.

[3] KANAMORI K., FUMOTO T., KOTERA H., *A color transformation algorithm using prisminterpolation*, IS&T 8th International Congress on Advances in Non-Impact Printing Technologies, 1992: 477-482.

[4] XU B.H., *Research on display color space conversion model based on 3D lookup table interpolation algorithm*, Packaging Engineering **32**(5), 2011: 77-79.

[5] ZHAO T.M., LIU S.D., *Inverse color space conversion algorithm based on cube induction*, Packaging Engineering, **38**(17), 2017: 200-205.

[6] BOLDRIN E., SCHETTINI R., *Faithful cross-media color matching using neural networks*, Pattern Recognition **32**(3), 1999: 465-470. https://doi.org/10.1016/S0031-3203(98)00037-5

[7] XU Y.F., LIU W.Y., WU B., *et al.*, School of Printing & Packing Engineering, Beijing Institute of Graphic Communication, Beijing 102600, China College of Precision Instruments and Opto-electronics Engineering, Tianjin University. Tianjin 300072, China. Application of a Neural Network in Color Conversion[C]. 2006: 89-93.

[8] ZHAO T.M., *Research on color space conversion algorithm based on 3D look-up table method*, Strategic Support Force Information Engineering University, Zhengzhou, 2018.

[9] ZHANG Q., *A color space transformation model based on RBF neural network*, Packaging Engineering, **30**(5), 2009: 71-73.

[10] LI P.F., NING Y.W., JING J.F., *Research on the detection of fabric color difference based on T-S fuzzy neural network*, Color Research and Application, **42**(5), 2017: 609-618. https://doi.org/10.1002/col.22113

[11] MacDonald L., *Color space transformation using neural networks*, [In] *Proc. IS&T 27th Color and Imaging Conference*, 2019: 153-158. https://doi.org/10.2352/issn.2169-2629.2019.27.29
[12] Saravanan G., Yamuna G., *Real-time implementation of various color space models*, International Journal of Circuits and Architecture Design **2**(3/4), 2016: 258-271.
[13] Yang J.K., Li P.F., Su Z.B., *et al.*, *An improved limit learning machine based color space conversion method for digital printing*, Advances in Lasers and Optoelectronics **58**(05), 2021: 343-348.
[14] Zhao C.F., *Theoretical and practical research on computer color matching*, Xi'an University of Technology, Xi'an, 2004.
[15] Liu C.H., Li Z., Xu C., *et al.*, *Deep neural network-based BRDF model for common materials of spatial targets*, Journal of Optics **37**(11), 2017: 358-367.
[16] Gong J.M., Liu F., Wu Y.J., *et al.*, *Design scheme of Raman fiber amplifier based on neuronal network and artificial bee colony algorithm*, Journal of Optics **41**(20), 2021: 24-32.
[17] Hu Z.Q., *Research on automatic temperature recognition method of oscillating paint based on camera color characterization*, Beijing University of Technology, Beijing, 2020.
[18] Han X.H., *Research on the quality inspection method of color prints based on image processing technology*, Xi'an University of Technology, Xi'an, 2009.

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