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Article

Application of deep learning algorithm in color matching automation of packaging design

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Abstract: Color has a strong psychological implication. In today's society, ordinary consumers not only require products to have corresponding functional uses but also seek their spiritual functions to ensure emotional communication between the product and the user. Therefore, the product color with emotional experience has become the goal pursued by enterprises, the spiritual connotation of color has also become the consumer's consumption requirements, and the perceptual image of the product determines whether consumers have a demand for the corresponding product. Based on this, this paper takes household electrical soybean milk machine as an example, using multi-scale analysis and cluster analysis methods to get the perceptual image vocabulary that can represent the color of product packaging. On this basis, BP neural network is used to establish the perceptual image vocabulary and product packaging color matching model. The simulation results show that it is feasible to establish the association model between perceptual image and color matching by BP (back propagation) neural network.

Keywords: deep learning; packaging color matching; bp neural network; color perceptual image; product color matching; package design

1. Introduction

In the real society, commodity packaging seems to be everywhere, which is a specific result of the gradual progress and increasingly perfect commodity society. The complex diversity of commodities allows us as consumers to have more references, and the unique appearance of commodities as the selected objects is crucial, which has become an important reason for influencing consumer choice to a large extent. Good packaging design must have shape elements, composition elements, material elements. Among them, composition elements as an important part of presenting the formal beauty and complete performance of packaging, color has played an important role.

The research on color collocation is also very extensive. Zhang [1] analyzed physiological signals such as heart rate and respiration by correlation and power spectrum, and established a nonlinear fitting mathematical model of color perception, so as to find out the law of influence of physiological characteristics on color stimulation. These laws and models can be used to further determine the human perception image of color through human physiological indicators. Ding [2] took consumers' perception of product color image as the research object, aimed at the practical application of product color design, and established a set of product color design methods that could adapt to changes in product characteristics and effectively meet consumers' real image needs. Zhao [3] builds a color intelligent design system that can meet people's expectation of color design. First, he models color and uses intelligent artificial algorithm to simulate human thinking characteristics in color

design, so as to realize intelligent color design. In the aspect of using deep learning to study color matching, Liu [4] proposed an effective discrete supervised fashion coordinate hash model in view of the high complexity of color visual features and the lack of purchase records of historical items. Luo [5] proposed a lightweight convolutional neural network clothing color classification method. The background was removed by YOLOv3 algorithm, and the Harris corner points, SIFT (Scale-invariant feature transform) features and HOG (Histogram of Oriented Gradients) features of clothing images were classified. Then, the feature algorithm was constructed by inputting the image color feature information through DenseNet model, thus completing the clothing color classification suitable for multiple occasions. Peng [6] puts forward a new method to extract the features of fashion items and conduct visual style modeling of fashion items by taking advantage of CNN (Convolutional Neural Network) to extract color attributes at different levels. After extracting the text and visual modal information of fashion items, PolyLDA model is used to fuse them, so as to construct a style vector for each fashion item [1–6].

It can be seen that most of the current color matching and perceptual image evaluation uses cluster analysis to obtain the evaluation value of perceptual image, and uses gray theory to establish the perception model of color and perceptual image. However, for complex perceptual image evaluation, cluster analysis method is difficult to capture the subtle differences and changes, which limits its accuracy and applicability. Based on this, this paper uses multi-scale analysis and cluster analysis methods to study the perceptual image of color and packaging color matching.

The research organization and innovation points of this paper are as follows: this paper adopts a combination of qualitative and quantitative methods, applies the relevant knowledge of color psychology, and obtains the perceptual image vocabulary that can represent the color of product packaging through multi-scale analysis and cluster analysis [7–9]. Taking soybean milk machine as an example, based on the research on the packaging color matching of soybean milk machine products, the perceptual intention words closest to 0 were obtained as the theory of soybean milk machine color matching, which laid the groundwork for the subsequent design of automatic packaging color matching model. On this basis, BP neural network is used to establish the perceptual image vocabulary and product packaging color matching model, and the feasibility of the model is simulated and analyzed, and finally the automatic decision program of packaging design color matching is given.

2. Color matching design theory

2.1. Objective attributes of color

No matter how people view color, no matter what media color is defined in, no matter what other senses respond to the stimulus brought by color, the experience of color is still on the visual level. Therefore, to study color, we must first pay attention to the three objective properties of color samples: hue, brightness, and saturation. Hue is the name of color [10]. Hue is people's first impression of colored things, and it is also the most important factor to distinguish various colors. Lightness refers to the degree of light and dark of the hue. Hue is cyclic and continuous, while lightness is linear and progressive. A lightness series must have a starting point and an ending

point. Whether there is a hue or not, there is a lightness contrast. Saturation refers to the intensity of the hue, or the proportion of solid colors contained in the color sample. The change of the three attributes of color will bring about different perceptual images, but the influence of the change of the three attributes on the perceptual images has certain rules.

2.2. Color psychology

The human psychology of color is a natural process, starting from the eyes, feeling, perception, and finally association, symbol, and so on. Therefore, the study of product packaging color matching should start from the psychological level of human beings, and find the application rules and methods of color through color psychology. The perceptual image of color is caused by human's unique perception of things, and it is a kind of inner activity of relatively high subjective nature. And color perception is the premise of the formation of perceptual image [11]. The perceptual image of color mentioned here is based on the premise of the formation of perceptual image, plus color elements, that is, when people see the color, integrate their memories and ideas, to obtain psychological feelings, in other words, color gives people some feelings or feelings.

3. The lexical analysis of product packaging color matching image based on color psychology

3.1. Selection of perceptual image vocabulary pairs

Taking household soybean milk machine as an example, the packaging color matching image vocabulary is analyzed. A network questionnaire was established, 35 industrial design graduate students and 7 professional teachers with industrial design background were investigated, and the most suitable perceptual image vocabulary pair for household appliance color was selected [12]. The top 20 eligible perceptual image word pairs were selected by voting, as shown in **Table 1** below.

Table 1. The lexical pairs of perceptual images of soybean milk machine.

Serial number	Word pairs	Serial number	Word pairs
1	Frugal-luxury	11	Female-male
2	Deluxe-plain	12	Elegance-unrestrained
3	Retro-trendy	13	Modern-ancient
4	Masculine-feminine	14	Rugged-delicate
5	Modern-home	15	Delicate-rough
6	Steady-bubbly	16	Orderly-casual
7	Soft-firm	17	sensation-reason
8	Casual-business	18	Clean-complex
9	Reserved-loud	19	Warm-cold
10	Nature-technology	20	Affinity-cold

3.2. Analysis of fitting degree of perceptual image vocabulary

The above designers were invited to classify the 20 pairs of words and fill the similar pairs into the same group of the questionnaire. All the 20 pairs of words are required to be filled in the table without repeating, but the pairs of words in each column of the table can be different. The frequency of each pair of words appearing in the questionnaire is counted, and the frequency similarity matrix of the pair of words is constructed to be expressed $A = (X_{ij})(i、\ j = 1,2,\ldots,20)$.

$$A = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1j} & \cdots & x_{120} \\ x_{21} & x_{22} & \cdots & x_{2j} & \cdots & x_{220} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ x_{i1} & x_{i2} & \cdots & x_{ij} & \cdots & x_{i20} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ x_{201} & x_{202} & \cdots & x_{20j} & \cdots & x_{2020} \end{bmatrix} \tag{1}$$

In the formula, x_{ij} is the frequency of the word's pairs of group i and group j appearing in the same group.

The fitting degree of the samples in space is determined by the stress coefficient, and the available range of dimensional coordinates is also determined by the pressure coefficient. The fitting degree between the observed distance of the model and the estimated distance is the pressure coefficient. Using the similar frequency matrix for multi-dimensional scaling analysis, first enter the frequency matrix to be tested [13]. If the dimensional coordinates can be used, then the data will be used for cluster analysis; if the dimensional coordinates cannot be used, then the data needs to be adjusted and re-verified. In the multidimensional scaling analysis, first of all, the fit degree of the model built above is analyzed, and the estimated distance is used to $\partial_{ij} = \Delta(\delta ij)$ represent. If the estimated distance calculated according to the multidimensional scaling analysis completely fits the observed distance, then there is $\partial_{ij} = d_{ij}$. In general, there is a certain difference between the two, that is, there is a residual. For this reason, the paper adopts the Stress coefficient formula to express the fitting degree between the observed distance and the estimated distance. Its expression is as follows:

$$stress = \sqrt{\frac{\sum_{i=1}^{20}\sum_{j=1}^{20}|\Delta(\delta ij) - dij|^2}{\sum_{i=1}^{20}\sum_{j=1}^{20} dij^2}} \tag{2}$$

The relationship between pressure coefficient and fit degree in multidimensional scale analysis is shown in **Table 2** below.

Table 2. The relationship between pressure coefficient and fit degree in multidimensional scaling analysis.

Kruskal pressure coefficient	**0.2**	**0.1**	**0.05**	**0.025**	**0**
Degree of fit	poor	Normal	good	optimal	Perfect

Stress refers to the Kruskal pressure coefficient, and the smaller the value, the better the fit. Through the above experiments, Spss was used for multi-dimensional scale analysis, and Stress = 0.06915 was obtained, with the result between "good" and

"ordinary", indicating that the cluster data for lexical pairs of perceptual images obtained by the multi-dimensional scale analysis method is valuable and reasonable and reliable.

The final obtained spatial coordinate data of 20 pairs of perceptual image words in 5 dimensions are shown in **Table 3**, where positive and negative signs indicate that the test samples are located in the positive and negative axes of the spatial coordinates.

Table 3. shows the spatial coordinate values of perceptual image words in 5 dimensions.

Word number	5-dimensional spatial coordinate values				
	1	**2**	**3**	**4**	**5**
V1	0.228	0.139	0.249	0.185	0.669
V2	0.720	2.737	1.495	1.254	0.429
V3	1.075	0.487	0.572	0.655	0.157
V4	0.406	1.101	0.663	0.148	0.062
V5	1.076	0.990	0.195	0.446	0.541
V6	2.046	0.535	0.068	1.225	0.939
V7	2.327	1.152	0.776	0.640	0.473
V8	0.838	1.120	0.301	0.194	0.735
V9	1.471	0.876	0.054	0.379	0.867
V10	1.728	0.658	0.478	0.793	1.061
V11	0.736	1.129	0.695	0.635	0.789
V12	1.006	0.656	0.153	1.906	0.790
V13	1.344	0.009	0.778	1.482	1.370
V14	0.079	0.795	1.743	1.141	0.131
V15	0.279	1.422	1.711	0.775	0.760
V16	0.681	0.850	1.211	0.936	1.263
V17	1.334	0.706	1.613	1.216	0.329
V18	1.095	1.580	0.283	0.552	0.139
V19	0.465	0.994	0.909	1.186	1.373
V20	0.612	0.022	1.434	0.521	1.869

3.3. Image vocabulary clustering based on K-mean cluster analysis

Table 4. Clustering results.

Cohort 1	Group 2	The third group	Fourth group	The fifth group
V8	V2	V3	V6	V20
V1	V18	V4	V7	V13
V5		V10	V17	V15
V9		V14		V19
V11		V16		
V12				

Spss software was used for cluster analysis of 20 groups of emotional words

representing the packaging color of soybean milk machine products, and the final cluster coordinates of emotional image words were obtained, as shown in **Table 4** below.

From the above clustering analysis, it can be seen that the closest ones in each group are V8, V2, V3, V6 and V20, and the five pairs of perceptual image words are representative perceptual image words. The most representative pairs of emotional image words in the 5 groups are V8 (casual-business), V2 (luxury-plain), V3 (retro-trendy), V6 (sedate-lively), V20 (amiable-cold). In this chapter, multi-scale analysis and cluster analysis were used to obtain the human perceptual intention words closest to 0 as the color matching of soybean milk machine, laying the foundation for the subsequent design of automatic packaging color matching model.

4. Construction of automatic color matching model based on bp neural network

BP neural network can have multiple layers, because this experiment uses a three-layer BP neural network model, so, in order to facilitate the description of the three-layer as an example to introduce. In the three-layer BP network, the number of input neurons is assumed to be M, the number of hidden layer neurons is I, and the number of output layer neurons is J [14]. The *m*-th neuron of the input layer is denoted as x_m, the *I*-th neuron of the hidden layer is denoted as k_i, and the *J*-th neuron of the output layer is denoted as y_j. The weight of the connection from xm to k_j is wmi and the weight of the connection from k_i to y_i is w_{ij}. The structure of the three-layer BP neural network is shown in **Figure 1** below.

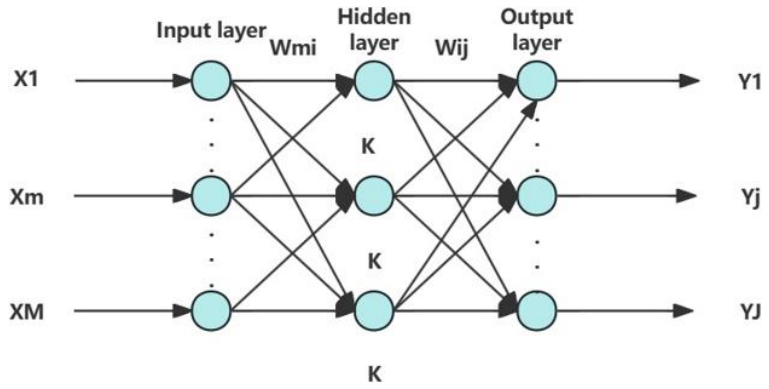

Figure 1. Structure of three-layer BP neural network.

In this paper, the color value is selected as the input layer, and the color scheme is obtained by analyzing the color matching samples of the product packaging, including the number of color matching colors, color values and the size of the proportion of the color area [15]. The RGB (Red-Green-Blue) color mode is adopted. The color sample of the product is coded according to the color days of the sample and the proportion of the area occupied by each color. p_{ij} (I =1, 2, ..., n; J = 1, 2, ... m) to represent the product color sample coding matrix, set the product packaging has a total of n color matching samples, each scheme has m colors, and according to the color proportion of the area decreasing.

The perceptual evaluation value is used as the output layer, and the Likert scale

method is used to score the obtained *n* color matching samples, and the average value is obtained by Tik (I = 1, 2, ..., n; K = 1, 2, ..., q) represents the product packaging color matching perceptual image evaluation matrix, specifically:

$$T_{ik} = \begin{bmatrix} \bar{M}_{11} & \bar{M}_{12} & \cdots & \bar{M}_{1k} & \cdots & \bar{M}_{1q} \\ \bar{M}_{21} & \bar{M}_{22} & \cdots & \bar{M}_{2k} & \cdots & \bar{M}_{2q} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \bar{M}_{i1} & \bar{M}_{i2} & \cdots & \bar{M}_{ik} & \cdots & \bar{M}_{iq} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \bar{M}_{n1} & \bar{M}_{n2} & \cdots & \bar{M}_{nk} & \cdots & \bar{M}_{nq} \end{bmatrix} \tag{3}$$

5. Simulation experiment of packaging color matching based on bp neural network

5.1. Color matching sample

Collected 123 images of various kinds of soybean milk machine on the Internet, except for the same color matching pictures, finally obtained a total of 50 color matching pictures. Research collected 123 soymilk machine structure, by 4 designers engaged in industrial design for many years to analyze and deconstruct the soymilk machine shape structure analysis, the results of the soymilk machine is mainly divided into the following parts, there are head, cup body, shell and so on. According to the analysis of experts, in order to unify the shape of the soybean milk machine, only change the color of the soybean milk machine, and build the soybean milk machine product as shown in **Figure 2** as the sample of this experiment. The shape classification of the soybean milk machine can be divided into lid, body, self-much and handle, and the appearance is composed of two colors.

Figure 2. Soybean milk machine shape analysis.

5.2. Experimental process

Taking the packaging color matching of soybean milk machine as an example, the two-color matching scheme was selected and BP neural network was used to simulate the color matching process of soybean milk machine on Matlab, and the corresponding simulation experiment results were obtained. Set the coding matrix of the packaging color sample of the soybean milk machine, and select the RGB value as

the attribute value for the soybean milk machine coding.

To set the hidden layer, we must first determine the number of hidden layer nodes, which is determined by Komogorov theorem. If the number of layers of the neural network is 3, and its first layer has m units, then its hidden layer has 2m+1 units. In the scientific research of the color matching experiment of this soybean milk machine, the first layer of this neural network has 6 elements, namely R1, G1, B1, R2, G2, B2, so the value of m is 6, and it is deduced that the number of neurons in the middle-hidden layer of the experiment should be 13.

In order to obtain the optimal solution, it is finally determined that the implicit layer adopts the Sigmoid tangent function, the hyperbolic tangent function's superior ability in dealing with nonlinear relationships, it can effectively capture the complex patterns in the data, while its output value ranges from −1 to 1, which helps in the subsequent processing and accelerates the training process of the neural network. The premnmx function is utilized to map the data linearly into the range of [0, 1] to enhance the training efficiency of the neural network and also to avoid the overfitting phenomenon to some extent. The output layer is normalized using the premnmx function and then calculated using the Sigmoid logarithmic function. Set the soybean milk machine product color matching neural network learning rate to 0.001, to ensure that the model gradually and stably adjusts the weights during the training process, to avoid the phenomenon of oscillation or instability due to the learning rate is too large. The number of training times is 1000. The traingdx function is selected as the training function, that is, the momentum gradient descent algorithm is used to train the BP neural network.

The above perceptual image word pair "affinity-cold" is taken as an example. Through the input vector input of test sample, the perceptual evaluation value of soybean milk machine color matching sample to the target word pair is finally predicted. Under the set parameters and input and output conditions, run the code, through 1000 times of training, and finally reach the training goal, the end of training, and get the ideal result as shown in **Figure 3**. The network measurement data results are shown in **Table 5**.

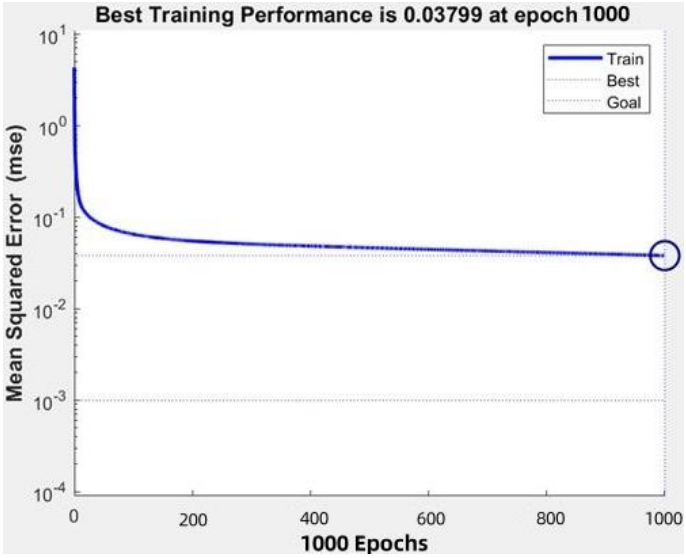

Figure 3. Network training results.

Table 5. Network measurement results.

Serial number	Affinity-cold	Luxurious-plain	Vintage-trendy	Casual-business	Sedate-lively
1	0.956	0.160	0.041	0.002	0.001
2	0.999	0.869	0.296	0.992	0.001
3	0.017	0.041	0.034	0.976	0.002
4	0.056	0.001	0.663	0.121	0.001
5	0.076	0.003	0.940	0.627	0.003

5.3. Verification of results

Standard deviation MSE can be used as a measure of uncertainty. When making repetitive measurements, the standard deviation of the set of measurements represents the accuracy of those measurements. Set a set of data as x_1, x_2, x_3, ..., x_N, whose average value isμ, then the formula for calculating MSE is:

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2} \tag{4}$$

MSE is used to evaluate the results of this experiment, at that time, indicating that the results are within the allowable error range. $\sigma \leq 0.01$The experimental results obtained are shown in **Table 6** below.

Table 6. Verification table of experimental results.

Vocabulary pairs	MSE
Affinity one cold	0.0036–0.01 or less
Deluxe-plain	0.0041–0.01 or less
Retro-trendy	0.0097–0.01 or less
Leisure-business	0.0075–0.01 or less
Sedate-lively	0.0003–0.01 or less

It can be seen from the data in the table that the MSE value of all data is less than 0.01 when the standard deviation results are verified, so the effectiveness of the results can be proved, and the feasibility of establishing the association model between perceptual image and color matching of products by using BP neural network is also proved.

6. Packaging design color matching automation decision program

The above simulation experiment verified the feasibility of using BP neural network to establish perceptual image vocabulary pair and product packaging color matching. In order to realize automatic packaging color matching of soybean milk machine, based on the above, Visual Basic visual programming software was used to design the program. The automated decision-making procedure for package design color matching given in this paper is a stand-alone color matching software that can be used not only for the color matching of soymilk machines, but also for the package color design of other products.

In the process of development, select the target perceptual image vocabulary pairs

in the vocabulary database from the drop-down menu of "color perceptual image vocabulary", enter the target evaluation value between 0 and 7 in the column of "target color image evaluation value", and click the button of "color matching sample generation" to obtain the color matching design scheme that meets the image. Among them, the smaller the image evaluation value, the more inclined it is to the words on the left of the word pair, while the larger the image evaluation value, the more inclined it is to the words on the right. The program output color matching design scheme, not only in the "color matching space characteristic quantity" column output each color in the scheme R, G, B attribute value, but also in the "generated color matching sample" column display the corresponding color sample, so that the designer can easily and intuitively see the color design scheme. Part of the design program code is shown in **Figure 4** below.

```
Imports System
Imports System.Drawing
Imports System.Windows.Forms
Public Class NeuralNetworkWrapper
Public Function PredictColorScheme(imageStyle As String) As ColorScheme
Dim colorScheme As New ColorScheme()
        colorScheme.PrimaryColor = Color.FromArgb(255, 128, 0)
        colorScheme.SecondaryColor = Color.FromArgb(255, 255, 0)
        Return colorScheme
    End Function
End Class
Public Class ColorScheme
    Public Property PrimaryColor As Color
    Public Property SecondaryColor As Color
End Class
Public Class MainForm : Inherits Form
    Private WithEvents btnPredict As New Button()
    Private WithEvents pnlPreview As New Panel()
```

Figure 4. Product color matching decision system.

7. Conclusion

To sum up, with the progress of science and technology and The Times, the market economy is becoming increasingly fierce, and product packaging plays an increasingly important role in the process of conveying information to consumers. In determining the outer packaging of products and the reaction of consumers, color has become a key factor, with a strong design aesthetic value. This paper introduces related concepts of color psychology, adopts multi-scale method to obtain perceptual image word pairs that can represent the color of soybean milk machine, and then uses BP neural network to establish the relationship between lexical pairs and packaging color matching. The experimental simulation is carried out for its feasibility, and the results show that it is feasible to establish the association model between perceptual image and color matching of products by using BP neural network. Finally, this paper gives the automatic decision procedure of color matching in packaging design, and realizes the automatic design of product guarantee color.

On the whole, the deep learning algorithm used in this paper for the design of packaging color matching has achieved the established research purpose. However, since the research in this paper is based on the soybean milk machine as an example, and only for the relationship between the two-color color scheme of the product and the perceptual imagery is studied, in reality, the color scheme of the product packaging

also needs to consider the multicolor color scheme, the texture of the product, etc. In addition, the sample size of this paper is relatively large, which may limit the ability of the model to be generalized. In addition, the sample size of this paper is relatively small, which may limit the generalization ability of the model. In the future research work, this paper will be used as the basis for further research on color matching studies that consider other factors of product development, and include more types of products to improve the generalization ability and practicality of the model, in order to provide more detailed help to product designers.

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Conflict of interest: The author declares no conflict of interest.

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