

The computer-aided design method of cabinet based on style imagery

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Abstract: Due to the practical problems of the high costs and the long development cycle of China's cabinet production, a computer-aided design method of the cabinet based on style imagery is proposed. According to the principle of the conjoint analysis method, the rough set theory and the weight coefficient of different components of the cabinet, a multi-dimensional model of style imagery to evaluate the cabinet is built. Then the related constants of style imagery are calculated and the cabinet components library is also built by the three-dimensional modeling. Finally, with recombinant technology and the mapping model between cabinet style and external characteristics, the prototype system based on Visual Studio is proposed. This system actualizes the bidirectional reasoning between product style imagery and the shape features, which can assist designers to produce more creative designs, greatly improve the efficiency of cabinet development and increase the profits of companies.

Key words: cabinet; computer-aided design; style imagery; component recombinant; shape features

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In recent years, with the development of industry technology, the demand of industry cabinets is booming. The cabinet market in China has reached an unprecedented stage of development. However, the domestic potential market is dominated by many famous international cabinet brands, such as Rittal, APC, HP and IBM. The main reason is that domestic cabinet manufacturers lack advanced design concepts, design styles and deep understanding of the design process. Therefore, how to effectively change the status quo, strengthen the overall design ability and improve the efficiency of cabinet production have become urgent issues for these domestic cabinet manufacturers at present.

The cabinet modeling design uses principles and rules of the space design to process all kinds of product structures, functions, materials and the relationships between

humans and the environment. However, most cabinet designers design products only according to their experience because they lack theoretical support. Besides, there are few studies on the product features of cabinets. Cheng^[1] analyzed the framework of cabinet case library by his in-depth knowledge of cabinet products and tried to create an aided design system to facilitate the improvement of designing industrial cabinets. Han^[2] summarized the modeling characteristics of cabinets in three different stages and proposed a theory model for humanization design of cabinet by combining humanized product design concepts. However, these studies only focused on designers' concepts and they were not comprehensive and systematic, which caused a failure to establish image mapping between cabinet characteristics and styles.

As an important aspect of emotional cognition, product style imagery becomes a key factor for distinguishing the consumer markets, and therefore it is of great significance to the design of industrial products. The perceptual technology based on the semantic difference method has been widely used in recent years. McCormack et al.^[3-6] carried out the detailed analysis of the style of different kinds of industrial products. Demirbilek et al.^[7] discussed the key role of product characteristics and users' emotions during the process of design. Chen et al.^[8] suggested that the product style should be made up of a series of model elements through different methods of special forms which was the main carrier of the mental function of the product. Huang et al.^[9-10] studied the application of perceptual technology in a computer-aided product design system. Zhu et al.^[11] proposed a new method which overcame problems of the old interior design method and improved the validity of the interior design. Pan et al.^[12] developed a prototype system about self-adaptive product design on modularity. Potocnik et al.^[13] presented a knowledge-based system which is capable of giving the designer high-quality support when making decisions from the aspect of modeling the reinforcement of a plate-press within a position of the maximum compressive load.

1 Related Work

In this paper, the characteristics-style mapping mechanism and the reasoning method based on style imagery of cabinet are studied. Then, the reference basis for cabinet design and technical support are proposed. Finally, the

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cabinet CAD prototype system based on the image style is created. This system can enhance the dynamic and continuous innovation of the cabinets, which has practical guiding significance and application value to the product design research and development of the cabinet enterprise. Based on people's cognitive principles, the method of cabinet style imagery modeling design takes user perceptual imagery semantic information into the quantization scheme to develop conceptual design, considering exterior modeling as the main object. Fig. 1 illustrates the research framework.

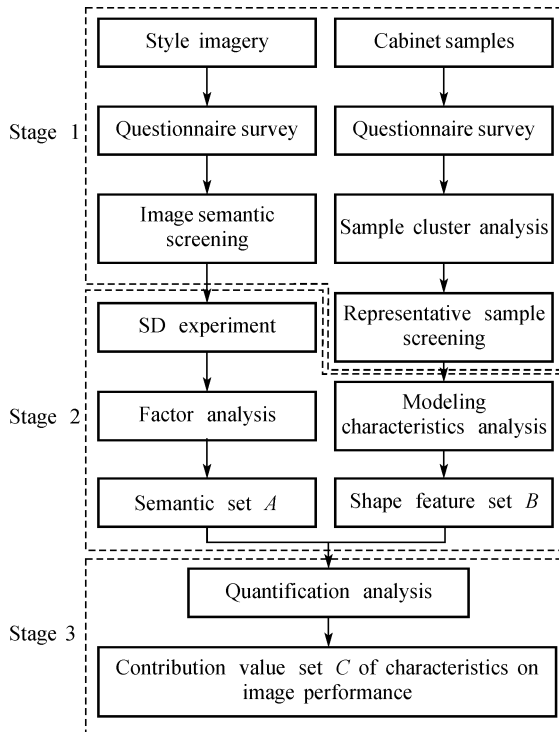


Fig. 1 Research framework

1) Cabinet samples and related imagerys are collected and organized. Cabinet samples are collected from the Internet and figure publications. Corresponding imagery linguistic variables are obtained through questionnaires conducted by cabinet designers and users. The typical cabinet samples are achieved by cluster analysis, and the related imagery linguistic variables are further screened in order to obtain the adjectives, which can correctly reflect cabinet perceptual cognition as far as possible.

2) The chosen imagery phrases and representative cabinet samples are performed in the imagery evaluation experiment by the semantic difference method. Factor analysis is implemented to the evaluated results in order to select several representative imagery semantics, which will make up the cabinet imagery semantic set *A*. In addition, cabinet designers and experts are invited to analyze the appearance of typical cabinet samples and decompose the cabinet modeling characteristics in order to establish the modeling feature set *B*.

3) Image semantic set *A* and the modeling feature set *B* obtained from the second stage are performed in the semantic difference evaluation experiment, in which the data is carried in the quantification analysis. Finally, the linear relationship between semantic and cabinet modeling characteristics is obtained.

2 Method

2.1 The description of the design style

Generally speaking, users are unable to make a direct and specific description of cabinet products by imagery perception. This study picks out more than 100 linguistic variables, which can be used to describe the cabinet products. Then, 30 subjects (including 20 people with solid design background and 10 people without design background) are invited to take part in the questionnaire experiment. They are required to choose the most suitable linguistic variables to describe the perceptual imagery semantics of cabinet products. The selected 15 pairs of linguistic variables are as follows: modern-traditional; simple-complex; individual-public; light-heavy; technological-fundamental; expensive-cheap; elegant-rugged; static-dynamic; ordinary-luxury; plump-lean; rational-emotional; rigid-pliable; graceful-tedious; deluxe-elementary and minimalist-mutative.

More than 120 pictures of cabinet samples produced by domestic or foreign companies are collected. After the discussion among the designers with solid cabinet design background, the similar samples are removed. As a result, 39 representative samples are preliminarily screened out.

2.2 Representative semantics selection

30 subjects measure the 39 cabinet samples with the 15 linguistic variables by the subjective evaluation method (The value is from -2 to 2). Correlation analysis is carried out on the 15 linguistic variables by SPSS. The result shows that the semantic correlation coefficients of simple-complex, ordinary-luxury and minimalist-mutative are extremely high, and the coefficients of other linguistic variables are very low. Therefore, these three linguistic variables are separated and the remaining 12 pairs of linguistic variables are analyzed by the factor analysis method. The value of KMO (Kaiser-Meyer-Olkin) test is 0.664, which means that the results conform to the requirement of the factor analysis. The principal component analysis is used to analyze the average value of the evaluated 12 linguistic variables. Result shows that factor 1, 2 and 3 can explain 97.602% of the total variance of the original variables, so it is rational to use the factor analysis method to analyze the data.

The data is analyzed by the method of orthogonal rotation. Tab. 1 shows that the five linguistic variables (light, rational, lean, rigid, static) have a high load on

the first factor, which can be defined as the feeling of being light. Another four linguistic variables (smooth, expensive, luxury, graceful) can be defined as the feeling of elegance and the three linguistic variables (modern, individual, technological) can be defined as the feeling of modernity. The last three linguistic variables (simple, ordinary, minimalist) can be classified into one category, defined as the feeling of simplicity.

Tab. 1 Component matrix of the 12 linguistic variables

Linguistic variables	Composition 1	Composition 2	Composition 3
Modern	0.365	0.495	0.784
Individual	0.424	0.433	0.779
Technological	0.454	0.443	0.760
Smooth	0.090	0.962	0.170
Expensive	0.154	0.785	0.477
Luxury	0.169	0.760	0.301
Graceful	0.258	0.894	0.332
Light	0.954	0.104	0.263
Rational	0.952	0.134	0.255
Lean	0.955	0.187	0.167
Rigid	0.950	0.116	0.282
Minimalist	0.925	0.234	0.172

2.3 Shape features reduction

Fig. 2 shows the 12 typical cabinets selected as experimental samples. In order to investigate the most important shape features of cabinet, 10 senior cabinet designers conduct morphological analysis of these samples by the

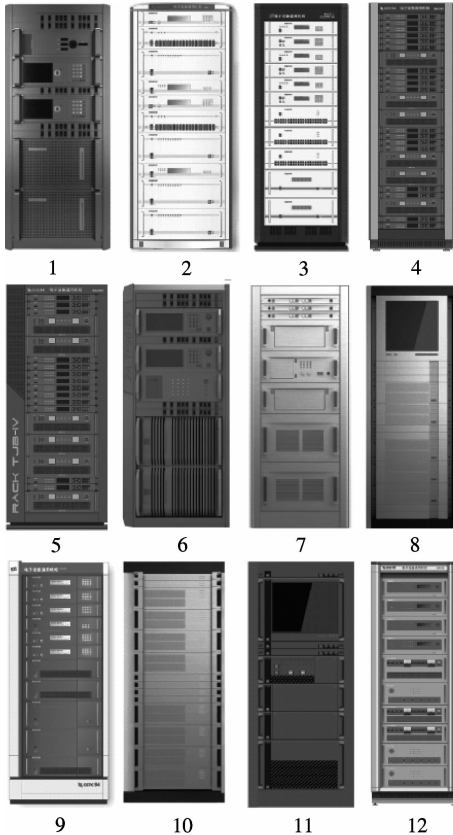


Fig. 2 Cabinet experimental samples

Delphi method. They extract and organize as many as possible of the morphological features of cabinet. In the first round, designers list more than one hundred morphological features to describe cabinets, such as square frame, round handle, thick base and so on, then they screen them into 20 typical features. Tab. 2 shows the final 8 typical features extracted by the second round of morphological analysis. Tab. 3 also shows the feature-style decision table by using the data discretization method.

Tab. 2 Feature-attribute table of cabinet

Features	Attributes
Frame	Horizontal, longitudinal
Head	No board, nameplate
Back	No decoration, decorative lines
Panel	Simple symmetrical, complex symmetrical, simple asymmetrical, complex asymmetrical
Handle	Square shape, cylindrical shape, hidden
Side	No decoration, decorative lines
Base	No base, thick base, thin base
Integral	Symmetrical, asymmetrical

Tab. 3 Features-style decision table of the 12 cabinet samples shown in Fig. 2

Cabinet number	Frame	Head	Back	Panel	Handle	Side	Base	Integral
1	1	1	2	4	1	2	1	1
2	2	2	1	1	2	1	1	1
3	1	2	1	2	2	1	3	1
4	1	2	2	2	2	1	1	1
5	2	2	2	2	2	2	3	2
6	1	1	2	4	1	2	1	2
7	1	1	1	1	1	2	1	1
8	1	1	2	3	3	1	1	1
9	2	2	1	2	2	1	2	2
10	2	1	2	3	1	2	2	2
11	1	1	1	3	1	1	1	1
12	1	2	1	4	2	1	1	1

Finally, we determine some key features of the cabinet appearance by the rough set theory. The definitions of redundancy, attribute reduction and attribute core in the rough set theory are as follows:

Definition 1 For the decision system $S = (U, CD, V, f)$, set $c_0 \in C$, if $P_c(D) = P_{(c \setminus \{c_0\})}(D)$, c_0 is the necessary attribute of D . If each c_0 in C is the necessary attribute of D , then C is the irreducible set of D . The set of irreducible attributes of D in C is called as the D core of C , marked as $c'_D(C)$. Set $C' \subset C$, $C' \neq \emptyset$, if ① $P_c = P_{c'}(D)$; ② C' is the irreducible set of D , and it is called as the reduced set of C , marked as $r_D(C)$.

Definition 2 The significance of C' for D is defined as $\alpha_{CD}(C')$, $\alpha_{CD} = [c(P_c(D)) - c(P_{(c-c')}(D))] / c(U)$. Based on Definition 1, Ohn^[14] proposed a genetic algorithm for attributes reduction, $f(B) = (1 - \beta) \cdot \frac{\text{cost}(A) - \text{cost}(B)}{\text{cost}(A)} + \beta \min \left\{ \varepsilon, \frac{|\sin S| |s \cap B \neq \emptyset|}{|S|} \right\}$. S

is the unrecognizable set in the decision table; β is the weight ratio between the loss reduction and the minimum classification rate; B is the subset of A , obtained by the evolution search algorithm; function $cost$ is the data actualizing correct classification; ε is the threshold value of the classification rate.

Using the method of the genetic algorithm, we delete feature attributes one by one to achieve the goal of subtracting the feature attribute, and obtain the set of the most significant (irreducible) features. Set $\alpha = 0.4$, $\varepsilon = 1.0$, and the set $A = \{\text{framework, panel, handle and base}\}$ is obtained; therefore, the cabinets can be decom-

posed into four different components as framework, insert box panel, handle and base.

2.4 Cabinet appearance and style imagery mapping

With the method of conjoint analysis, the impact of style imagery of various components on the whole cabinet can be quantized as the weight coefficient and the mapping model between modeling features, and style imagery can be established. 30 subjects with solid design background are invited to conduct SD evaluation experiment with a 5-point scale method. Tab.4 shows the values of different features on different style semantics.

Tab.4 Values of four different features of 12 typical samples on four style semantics

Features	Style	Cabinet number											
		1	2	3	4	5	6	7	8	9	10	11	12
Frame	Simple	0.6	0	-0.7	-0.2	-1.6	-1.2	1	1.9	-1.6	1.4	1.3	-1.3
	Elegant	-0.5	0.5	-0.4	0.7	0.6	-1.3	-0.1	0.7	0.6	0.6	-0.8	0.8
	Modern	0.5	-0.3	0.4	0.4	1	1	-0.8	1.3	0.5	1.3	-0.4	0
	Light	-1.2	0.9	-0.6	0	-1.3	-1.7	-0.4	0.6	-0.5	0.5	-0.9	-0.3
Panel	Simple	-0.6	0.4	-0.4	-1.9	-1.7	-1.4	1	2	-0.6	1.4	0.5	-1.7
	Elegant	0	0.8	0	0.8	0.6	-1.5	0.3	1.5	0.5	0.9	0.3	0.2
	Modern	-0.6	0.4	0.1	0.7	0.6	0.2	0.2	1.6	0.6	1.5	0.8	0
	Light	-1.2	0.8	0	-1.3	-1.6	-1.7	0.2	0.8	-0.5	1.1	0	-0.4
Handle	Simple	-0.3	1.6	1.3	1.1	0.4	-0.7	-0.6	2	1	-1.2	-0.9	0.5
	Elegant	-1.3	1	0.5	0.4	0.6	-0.9	-0.4	1	0.6	-0.1	-0.2	0.5
	Modern	0.6	-0.2	0	0.4	0.5	0.8	-0.6	1.9	0.1	1.2	0.6	0.5
	Light	-1.6	1.6	1.3	1	0.8	-1.1	-0.7	1.2	0.6	-0.7	0.1	1
Base	Simple	0.6	-0.1	-0.9	-1.2	-0.4	0.5	0.8	1.2	-1.1	1	1.2	-1.4
	Elegant	0.4	0.7	0	1.2	0.7	0.1	0	0.6	-0.2	0.1	-0.5	0.6
	Modern	-0.5	0.1	1	0.5	1.2	0.1	-0.4	0.7	0.9	0.3	-0.3	0.1
	Light	-0.3	0.7	-0.1	-0.3	-0.9	-0.4	0	0.6	-1	0	-1.1	0.1
Overall	Simple	-0.1	0.8	-1	-1.7	-1.9	-1.5	1.2	2	-1.3	1.3	0.7	-1.7
	Elegant	-0.9	1	0	1	0.7	-1.6	-0.1	1.6	0.4	0.9	-0.4	0.6
	Modern	0.1	-0.1	0.6	0.7	1	0.4	-0.7	1.7	0.8	1.6	0.4	0.2
	Light	-1.3	1.1	-0.3	-0.5	-1.4	-2	-0.1	0.9	-1.1	0.4	-0.9	-0.2

3 Results

According to the principle of the conjoint analysis method, the score of the whole cabinet Y can be expressed as the multi-dimensional linear model composed of independent variables of components scores:

$$Y = x_1A + x_2B + x_3C + x_4D + R$$

where A is the value of frame; B is the value of panel; C is the value of handle; D is the value of base. Tab. 5 shows the results of mutiple linear regression analysis. With the weight coefficient of different parts of the cabinet in different style imageries and the constants shown in Tab.5, the calculation formulae of style imagery values can be obtained (see Tab.6).

Tab.5 Results of multiple linear regression analysis

Variables	Cabinet style imageries			
	Simple	Elegant	Modern	Light
R	-1.070 (-1.006)	-0.097 (-1.300)	-0.022 (-0.301)	-0.080 (-1.262)
A	0.335 (2.257)	0.332 (2.088)	0.271 (1.456)	0.461 (3.280)
B	0.685 (4.869)	0.584 (4.685)	0.343 (2.679)	0.352 (3.965)
C	0.058 (0.518)	0.391 (3.651)	0.379 (1.968)	0.116 (2.054)
D	0.153 (0.778)	0.180 (1.306)	0.365 (2.353)	0.464 (3.781)
R^2	0.956	0.964	0.927	0.971
F	60.904	73.678	35.958	92.399

Tab. 6 Formulae of different style imagery values

Style	A	B	C	D	R	Formulae
Simple	0.335	0.685	0.058	0.153	-0.107	$Y = 0.335A + 0.685B + 0.058C + 0.153D - 0.107$
Elegant	0.332	0.584	0.391	0.180	-0.097	$Y = 0.332A + 0.584B + 0.391C + 0.180D - 0.097$
Modern	0.271	0.343	0.379	0.365	-0.022	$Y = 0.271A + 0.343B + 0.379C + 0.365D - 0.022$
Light	0.461	0.352	0.116	0.464	-0.080	$Y = 0.461A + 0.352B + 0.116C + 0.464D - 0.080$

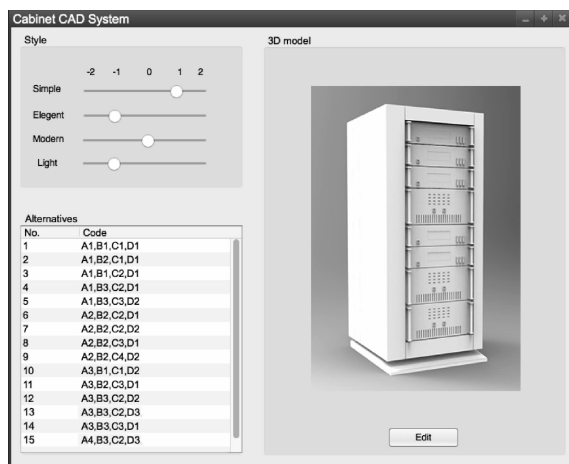
Fig. 3 shows the cabinet computer-aided design system established by using Visual Studio. It consists of the calculation and recognition of cabinet style imagery, alternative selection and edition of the cabinet samples, presentation of 3D models and representative values. The libraries of style imagery and product characteristics play a key role in the whole system. The specific steps are as follows:

1) Select different imagery variables and give each variable corresponding value, and the system will present a series of eligible alternatives.

2) Select an alternative, and the 3D cabinet model will be presented.

3) Click the “Edit” button, the four components can be replaced by different options, while the four imagery scores will change accordingly.

4) Click the “Picture” and “Model” buttons to export the corresponding pictures and models to aid the designer to design cabinets.

**Fig. 3** Cabinet computer-aided design system

4 Conclusion

In this paper, the style imagery model of the cabinet is built and the aided innovation design system of cabinet is proposed. According to the conjoint analysis method, a series of weight coefficients of various components and related constants is obtained. Then, the mapping model between the style imagery and external characteristics is established. Finally, with the cabinet product style imagery evaluation model and 3D recombinant technology, the cabinet aided design system is developed. The system is verified by practical application and feasibility, in addition. At present, the optimized version of this system is

adopted by some cabinet manufacturers, and thus the companies have obtained certain economic profits.

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基于风格意象的机柜计算机辅助设计方法

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摘要:针对国内机柜产品成本高和开发周期长的实际问题,提出了一种基于风格意象的机柜计算机辅助设计方法.根据联合分析法原理、粗糙集理论以及机柜各组成部件的权重系数,建立了机柜风格意象评价的多维模型.计算得到了各风格意象的相关常量及系数,并通过3D模型建立了机柜组件库.最终,结合组件重组技术以及机柜产品风格与特征之间的映射模型,基于Visual Studio软件开发了原型系统.该系统实现了产品风格意象与造型特征的双向推理,辅助设计师进行创新设计,大大提高了机柜研发的效率,提升了企业的经济效益.

关键词:机柜;计算机辅助设计;风格意象;部件重组;造型特征

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