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Designers' Cognitive Thinking Based on Evolutionary Algorithms

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Abstract

The research on cognitive thinking is important to construct the efficient intelligent design systems. But it is difficult to describe the model of cognitive thinking with reasonable mathematical theory. Based on the analysis of design strategy and innovative thinking, we investigated the design cognitive thinking model that included the external guide thinking of "width priority-depth priority" and the internal dominated thinking of "divergent thinking-convergent thinking", built a reasoning mechanism of design information with the thinking mathematics theory and established a product image form design model with the generalized interactive genetic algorithm. The example of testing machine form design shows that the method is reasonable and feasible.

Keywords: *cognitive thinking, image apperceive, product form, image design*

1. Introduction

Product images are the association of ideas of product form generated in thinking [1]. Ideal design concept depends largely on designers' profound insight to product images. Product image form design is based on human's visual perception, it develops design scheme with product form factors and non-rational Kansei cognitive information [2-3]. It is mainly based on the theory of "Kansei Engineering" [4], where "improving the Kansei Engineering System with artificial intelligence" [5-7] is one of the difficult and hot research. And based on thinking science [8], the study on designers' cognitive thinking [9-10] is an effective way of solving this problem. But the related studies [11-12] paid more attention to the simulation of design thinking and less attention to cognitive thinking in conceptual design, so there is a lack of effective way of solving problems such as the simulation of designers' cognitive thinking and the decision-making fatigue to morphological evolution.

To solve these problems, we analyze designers' cognitive thinking in the product image form design process and develop a image design thinking network model using the generalized interactive genetic algorithm; Finally, we take testing machine as an example, and the result shows that this method is reasonable and feasible.

2. Designers' Image Design Thinking

2.1. The Cognitive Thinking of Design

The cognitive thinking of design aims to seek the thinking modules of good design and their internal relations from design behavior, design process and their relations with the innovativeness of design. In the product design process, we seek the general rule of cognitive thinking through the study of designers' innovative thinking, design strategy, thinking mode and their relationship.

(1) Innovative thinking. In accordance with the answer search direction, the innovative thinking is divided into divergent thinking and convergent thinking. Divergent thinking is the mutability thinking process from one factor to several factors of design task or from one concept to another concept, and it applies to generate original and larger progressive design schemes; convergent thinking is the thinking process from a number of factors into a single factor of

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design tasks, and it applies to assess and transform design schemes into the physical structure [13]. In the product design process, designers achieve the novel schemes through divergent thinking and assess them through convergent thinking.

(2) Design strategy. "Width priority-depth priority" is a structured design strategy [14], and it is the universal principle that converts and deepens the design focus. "Width priority" is a design activity that designers use the extension strategy preferentially in the design process; it expands the problem space from a design concept to another. "Depth priority" is a design activity that designers use the detailing strategy preferentially in the design process; it deepens the problem space with the detailing of design elements. Designers generally use the "width priority" strategy to enrich schemes in the early stage and apply the "depth priority" strategy to improve the schemes in the later stage.

(3) Thinking mode. Designers' thinking can be described with the thinking chain, thinking chain bundles and thinking network in the mathematical theory of thinking [15]. Starting from the input design information, the thinking chain is a process that processing the existing information in memory and the necessary external information to create a new information. If the process produces much new information, it is called the thinking chain bundles. The thinking chain and thinking chain bundles can be described with the thinking logic function. Several thinking chain and thinking chain bundles constitute a thinking network. The designers' cognitive thinking model is shown in Figure 1.

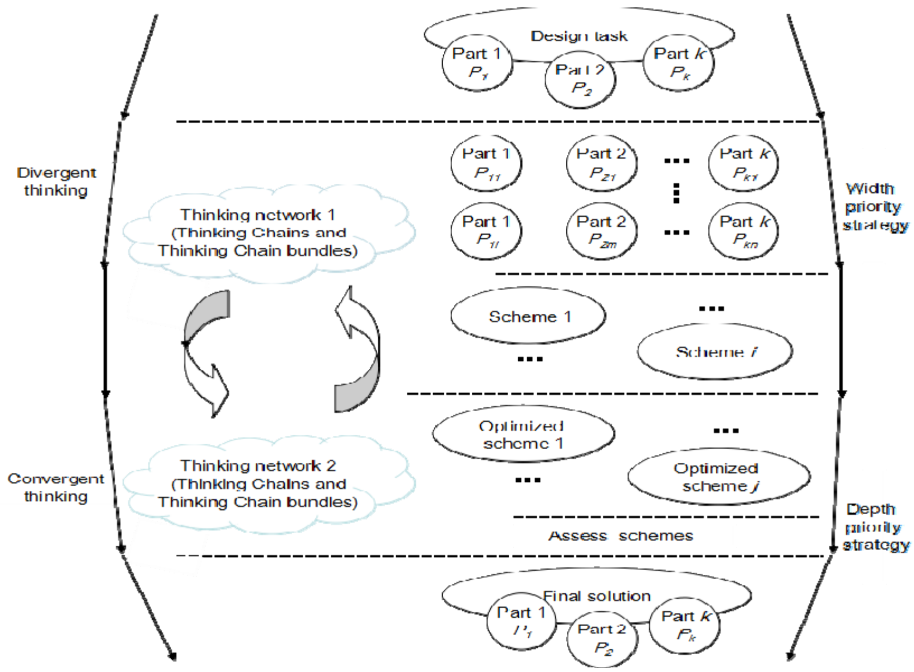


Figure 1. Cognitive Thinking Model of Design

"Width priority - depth priority" strategy is the external guide thinking of design activities, and "divergent thinking - convergent thinking" is the internal dominated thinking of design activities. In the scheme search process, the "width priority" strategy corresponds to the "divergent thinking" that contains many divergent thinking chain and thinking chain bundles that form the divergent thinking networks 1; in the process of detailing and program evaluation, the "depth priority" strategy corresponds to the "convergent thinking" that contains a number of convergent thinking chain that form the convergent thinking network 2. Designers' cognitive thinking process is the cycle of the two thinking network.

2.2. The Model of Product Image Form Design

Product image form design is a synthetic image behavior that assembles some certain material to formulate product shape, color and so on for the specific purpose. From the perspective of cognitive thinking, it is a process from information analysis to best answers, and the process is consistent with the genetic algorithm that simulates the biological principle "survival of the fittest" [16]. Generalized interactive genetic algorithm [17] is an evolutionary optimization algorithm based on human - computer interaction. The human - computer interaction is not just for the fitness evaluation of individuals, but it also includes other manual intervention on the evolutionary process. The optimal design of product image form is not only about image evaluation, but it is also about functionality, manufacturability and user acceptability and so on that require more manual intervention. Therefore, in this study, we simulate the design process of product image form with the generalized interactive genetic algorithm, and the model is shown in Figure 2.

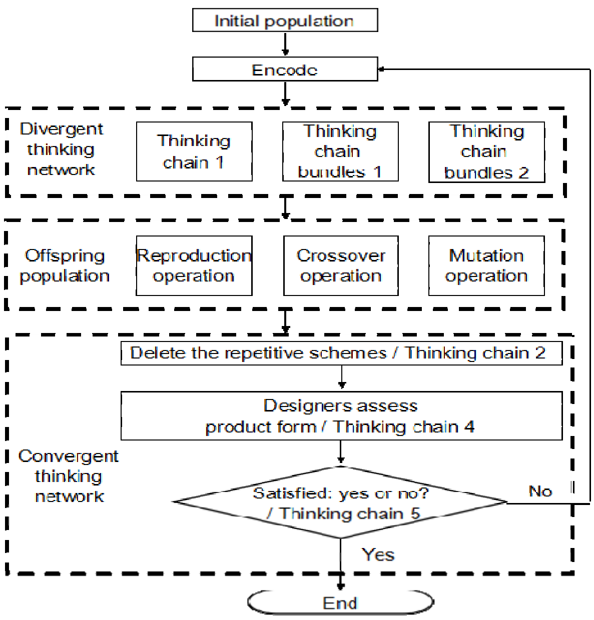


Figure 2. Image Design Thinking Model Based on the Generalized Interactive Genetic Algorithm

(1) In the early stage, designers research existing products and their development trends and select a number of products as the design reference that constitutes an information group that corresponds to the initial population of the generalized interactive genetic algorithm. There are m individuals in the initial population P, and $P = [P1, P2, ..., Pm]$. Each individual P_i has n attributes, and $P_i = [p_1, p_2, ..., p_n]$. Each attribute p_j is determined by the respective parameter d, and $p_j = [d_{j1}, d_{j2}, ..., d_{jk}]$. P is the input information of cognitive thinking.

(2) The initial population is encoded as the input information of cognitive thinking. We simulate designers' divergent thinking with the genetic algorithm operation reproduction, crossover and mutation using the "width priority" strategy. The reproduction operation corresponds to the thinking chain 1, and it can be written as:

$$tc_1(P - f_1 - P^r)$$

The crossover operation corresponds to the thinking chain bundles 1, and it can be written as:

$$tcb_1(P - f_2 - P^c)$$

The mutation operation corresponds to the thinking chain bundles 2, and it can be written as:

$$tcb_2(P - f_3 - P^m)$$

They constitute designers' divergent thinking network.

P_i is the individual of the generalized interactive genetic algorithm and corresponds to a binary string U_i, $U_i \in \{0,1\}^l$, and l is the length of the code. If $u_k = \{0,1\}^{lk}$ corresponds to the kth parameter d_k of P_i, u_k is called the kth gene unit of P_i .

P_i corresponds to the tuple e_i of relation R, and the offspring individual P_i^r of reproduction operation corresponds to the tuple e_i^r of relation R. With the generalized Cartesian product operation, the thinking logic function of reproduction operation can be written as:

$$e_i^r = \prod_{\{u_1, u_2, \cdots, u_n\}} (e_i)$$

P_i and P_j respectively correspond to the tuple e_i and e_j of relation R. If the crossover locus locates between the gene unit u_{c-1} and u_c, the offspring individuals P_i^c and P_j^c of crossover operation correspond to the tuple e_i^c and e_j^c of relation R. The thinking logic function of crossover operation can be written as:

$$\begin{cases} e_i^c = \prod_{\{u_1, u_2, \cdots, u_{c-1}\}} (e_i) \times \prod_{\{u_c, u_{c+1}, \cdots, u_n\}} (e_j) \\ e_j^c = \prod_{\{u_1, u_2, \cdots, u_{c-1}\}} (e_j) \times \prod_{\{u_c, u_{c+1}, \cdots, u_n\}} (e_i) \end{cases}$$

P_i corresponds to the tuple e_i of relation R. If the mutation locus locates on the gene unit u_c and its attribute value of the gene unit is $d_i(u_c)$, the attribute value of the mutated gene unit is $d_j(u_c)$, and $i \neq j$. The offspring individual P_i^m of mutation operation corresponds to the tuple e_i^m of relation R. The thinking logic function of mutation operation can be written as:

$$e_i^m = \prod_{\{u_1, u_2, \cdots, u_{c-1}\}} (e_i) \times d_j(u_c) \times \prod_{\{u_{c+1}, u_{c+2}, \cdots, u_n\}} (e_i)$$

The three thinking logic functions constitute the thinking logic function family of the divergent thinking network that simulates the search process of schemes. And the result of the divergent thinking network is denoted as Q and corresponds to the offspring population of the generalized interactive genetic algorithm:

$$Q = P^r \cup P^c \cup P^m \ .$$

(3) The repetitive codes in the set Q are simplified to get a compact set Q^s, and $Q^s \subset Q$. It simulates the process that designers pick out the repetitive design schemes and keep one of them. And the process corresponds to the thinking chain 2 that can be written as:

$$tc_2(Q - f_4 - Q^s)$$

Q_i and Q_j are codes in the set Q and respectively correspond to the tuple e_i and e_j of relation R. The thinking logic function of the thinking chain 2 can be written as:

$$\begin{cases} e_i = \prod_{\{u_1, u_2, \cdots, u_n\}} (e_i) \\ e_j = \prod_{\{u_1, u_2, \cdots, u_n\}} (e_j) \end{cases}$$

If e_i=e_j, Q_i=Q_j.

(4) Designers comprehensively assess the schemes Q_i^s in the set Q^s by their subjective perception, manufacturing processes, costs and other design requirements and accordingly select m schemes to obtain a solution set Q^w. This process corresponds to the thinking chain 3 that can be written as:

$$tc_4(Q^u - f_6 - Q^w)$$

The thinking logic function of the thinking chain 3 is:

$$I^u = F(Q^u, S, M)$$

Here: I^u is the set of the comprehensive assessment of the schemes in the set Q^u; S is designers' subjective perception; M is manufacturing processes, costs and other design requirements.

(5) Designers assess the schemes Q_i^w in the set Q^w according to the design expectation I^d. If some solutions meet the design expectation, the system outputs Q^w; otherwise, the system goes back to step (2) and begins the next thinking cycle as Q^w sever as parent population. This process corresponds to the thinking chain 4 that can be written as:

$$tc_5(Q^w - f_7 - P)$$

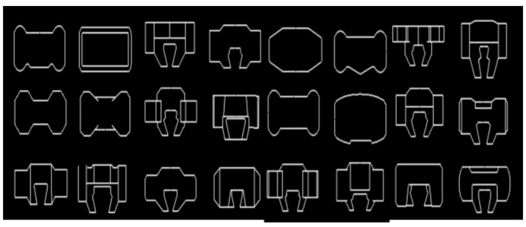
If the scheme comprehensive assessment of Q_i^w is I_i^w that form the set I^w, the thinking logic function of the thinking chain 4 is:

$$\begin{cases} I^d \in I^u, & \text{ends and outputs } Q^w; \\ I^d \notin I^u, & \text{goes back to step (2).} \end{cases}$$

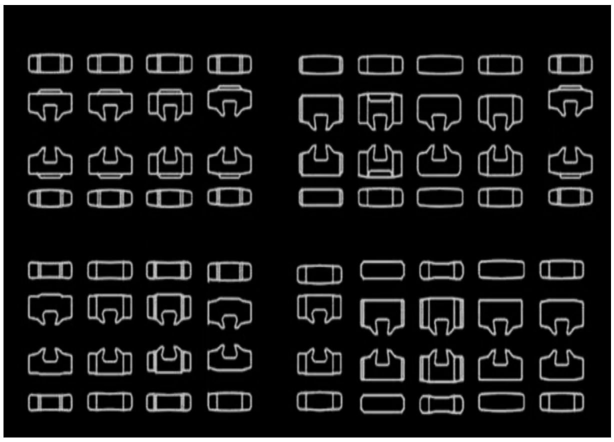
The thinking chain 2, thinking chain 3 and thinking chain 4 constitute the designers' convergent thinking network. The thinking network assesses and selects schemes with the design expectation.

When the assessments of the schemes approach the design expectation, the crossover rate and mutation rate decrease accordingly. And designers concentrate to deepen the problem space.

3. Case study



(a) Original form of beam



(b) New form of beam

Figure 3. The Design of Beam

We take the testing machine as the study object, and the case study comes from the Tianshui Hongshan Testing Machine Ltd. The designer (Shengpeng Zhao) select 79 product images and 50 vocabularies from internet. The product samples and image adjectives are excluded by KJ method. 27 product samples (shown in Table 1) and 2 Kansei vocabularies (plain-modern, feminine-masculine) are selected.

Based on the previous work (Product Form Identification Technology Based on Cognitive Thinking, accepted by TELKOMNIKA Indonesia Journal of Electrical Engineering), Zhao focus on the design of light bars and screw on the top, top view of beam, front view of beam, ratio of upper and lower, the number ratio of light bars and screw to design the product with the image of modern. Zhao expands schemes with the divergent thinking that corresponds to the thinking network 1. And the form of beam is shown in Figure 3.

Table 1. 27 Representative Samples

Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
				
Sample 6	Sample 7	Sample 8	Sample 9	Sample 10
				
Sample 11	Sample 12	Sample 13	Sample 14	Sample 15
				
Sample 16	Sample 17	Sample 18	Sample 19	Sample 20
				
Sample 21	Sample 22	Sample 23	Sample 24	Sample 25
				
Sample 26	Sample 27			
				

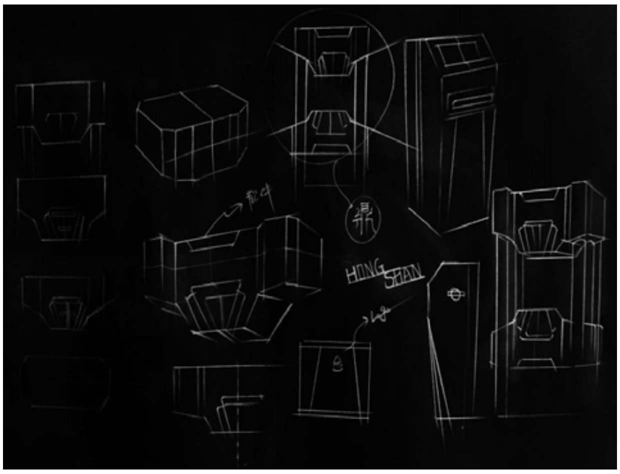


Figure 4. Part of the Sketches

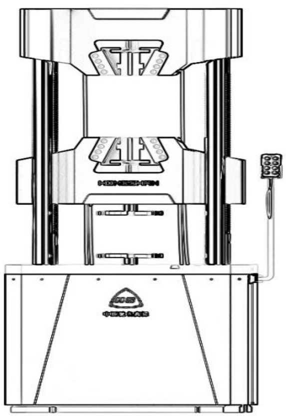


Figure 5. The Overall Shape of Testing Machine

Figure 6. The Original Product

(a) New Product at the Show (b) A Suite of Products

Figure 7. The New Product

Based on these new schemes, Zhao draws many sketches, selects and optimizes obtained forms and assesses sketches to find out the suitable one. In this stage, Zhao deepens the problem space with the convergent thinking that corresponds to the thinking network 2. The sketches are shown in Figure 4, and the overall shape of testing machine is shown in Figure 5.

Finally, Zhao designs a color scheme: the main machine body adopts the low brightness gray that gives a feeling of simple and elegant, and neutral colors adapt to different environments and can weaken operator's psychological pressure; small area of Orange (enterprise standard color) increase the aesthetics of machine as decoration. The sales show that the design is successful and the product identity is improved. And the original product and new product are shown respectively in Figure 6 and Figure 7.

4. Conclusion

We analyze designers' image design thinking and build the Cognitive Thinking-based Computer Aided Industrial Design (CT-CAID) model with generalized interactive genetic algorithm. Case study shows that it is reasonable and feasible. The research conclusions are mainly summarized as follows: The thinking network that is constituted with thinking chains and thinking chain bundles is in accordance with the external guide thinking of "width priority - depth priority" and internal dominated thinking of "divergent thinking - convergent thinking" in the reasoning process of design information. The thinking network in this paper lays the foundation for the quality evaluation of thinking with the mathematical theory of thinking in the following study.

Acknowledgements

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