Key Technologies of Product Design Evolution Based on Case-Based Reasoning

Licheng Zong*

College of Art, Northwest University, Xi'an shaanxi China

zonglicheng@nwu.edu.cn

*corresponding author

Keywords: Case-based Reasoning; Product Genes; Gene Networks; Innovative Design

Abstract: From the perspective of intelligent design, using biological evolutionary populations and evolutionary theories, introduce complex network concepts, research on product population reasoning technology for product evolutionary design, Constructed product instance definition and expression in product instance reasoning, integrating complex network technologies to build gene networks for product examples, introduction of interactive network topology thinking in biological proteins, gene mining and optimization scheme in establishing product instance gene network, construction of a product evolutionary design model based on case-based reasoning.

1. Introduction

Manufacturing is an important pillar of global economic development, with the increasing demand for product diversity, personalization and innovation, with the development of intelligent technology and computer-aided technology, the research of product innovation design has entered a whole new field. Intelligent and innovative design has become a new direction for product design, especially with the development of computer-aided technology, case-based reasoning[1], design examples, and reuse of design knowledge have become important research directions and contents of intelligent CAD technology. In previous product designs, knowledge acquisition[2] and reuse[3] are the main research directions of product innovation. Case-based reasoning technology in recent years[4], to some extent, it has made up for the shortcomings of design knowledge acquisition and reuse technology. However, this type of case-based reasoning technology can often only retrieve cases, the acquisition of design solutions requires manual intervention and intervention by design experts[5]. Based on evolutionary algorithms, product population gene design method considering case-based reasoning provides possibility for intelligent automation design of product innovation schemes[6]. A key element in implementing such technologies is the study of the genes of the product instance population, classify product design examples, establish product instance population, extracting product design example population genes, taking product instance population genes as evolutionary conditions, combining evolutionary reasoning techniques, innovative design of this type of product population.

2. Product innovation design and case-based reasoning

Product innovation design is a general concern in industrial design. Designers through the use of certain principles and methods, the process of developing creative ideas and combining new technologies, principles and methods to develop innovative products. From the perspective of the entire product life cycle, product innovation design includes conceptual design stage, product model design stage, product service and interaction mode stage, and product sales and maintenance stage. Design principles and methods that are widely used now have theory of Inventive problem solving(TRIZ),quality function deployment(QFD),value engineering(VE),comprehensive design methodology(CDM), modular design(MD),axiomatic design(AD),feature design[7],creative template approach(CTA) [8],portfolio creation method(PCM)[9],innovative engineering methods for complex products[10].

The currently used reasoning methods are rule based reasoning (RBR), case based reasoning (CBR) and model based reasoning (MBR)[11]. case based reasoning (CBR) is a hot topic in the field of artificial intelligence in recent years. The CBR method uses an inference-based model, use existing product development technology, product design methods, problem solving experience and methods to solve new problems, in line with the way people think[12].

3. Key Technologies of Product Case Reasoning

3.1 Definition and expression of product examples

In biologically, population refers to the time and space, a collection of all individuals of the same species. This collection is not a mechanical collection, Instead, the population genes are passed on to offspring through mating, population is the basic form of species existence and the basic unit of species evolution. In order to more clearly explain the function model, structure model and principle model of the product instance population, Establish a tree-level product instance population hierarchical expression model.

The product instance tree can be expressed as follows:

$$P_C = Tree(N_{C,i}) \tag{1}$$

In the formula, P_C is a product instance, $N_{C,i}$ is the i node on the instance tree, $i = 1, 2, ..., n$, n Is the total number of nodes on the tree.

$$N_{C,i} = f(N_{F,i}, N_{P,i}, N_{S,i}, G_{N,i}) \tag{2}$$

$N_{F,i}$ is the function node of the instance node, $N_{P,i}$ is the principle node, $N_{S,i}$ is a structural node, $G_{N,i}$ is the node gene, f Is the mapping relationship between nodes, expressed as follows:

$$\begin{aligned} N_{F,i} &= (A_{NF}, C_{NF}, M_{NF}, I_{NF}) \\ N_{P,i} &= (A_{NP}, C_{NP}, M_{NP}, I_{NP}) \\ N_{S,i} &= (A_{NS}, C_{NS}, M_{NS}, I_{NS}) \end{aligned} \tag{3}$$

A_{NF}, A_{NP}, A_{NS} are the characteristic attributes of functions, principles, and structural nodes, C_{NF}, C_{NP}, C_{NS} are the feature constraints of the corresponding nodes, M_{NF}, M_{NP}, M_{NS} is the operation method of the corresponding node, I_{NF}, I_{NP}, I_{NS} is the interface of the corresponding node.

After obtaining the product instance gene, product instance genes need to be encoded and expressed[13],this step is also to lay the foundation for later evolutionary design and genetic calculation. According to the product instance hierarchical decomposition tree model established above, Similarly, the product instance tree is expressed using the product gene tree. Product example gene expression is as follows:

$$G_C = tree(G_{N,i}) \tag{4}$$

In the formula, G_C is the tree-like genome of the product example, $G_{N,i}$ is the i node gene on the gene tree, $i = 1, 2, 3, ..., n$.

$$G_{N,i} = f(F_{GB,i}, S_{GB,i}, P_{GB,i}) \tag{5}$$

$F_{GB,i}$ is the functional gene of the node, $S_{GB,i}$ is the structural gene of the node, $P_{GB,i}$ is the principle gene of the node, f Is the relationship between the nodes, expressed as follows:

$$\begin{cases} F_{GB,i} = (A_{gf}, C_{gf}, M_{gf}, I_{gf}) \\ S_{GB,i} = (A_{gs}, C_{gs}, M_{gs}, I_{gs}) \\ P_{GB,i} = (A_{gp}, C_{gp}, M_{gp}, I_{gp}) \end{cases} \tag{6}$$

A_{gf} , A_{gs} , A_{gp} is a characteristic attribute of a gene, C_{gf} , C_{gs} , C_{gp} is a feature constraint, M_{gf}, M_{gs}, M_{gp} is the method of operation, I_{gf}, I_{gs}, I_{gp} is the genetic interface, express the relationship between function, structure, and principle genes.

3.2 Product gene network model construction

Product gene network is based on complex network theory, by clustering the basic shape information of the product, construct a network form that contains relative genes, so as to control and evolve product configuration through gene network. Construct a product gene network for case-based reasoning, it helps to understand and reason about the key factors in product configuration design from a cognitive perspective. Combining graph theory-related theories and methods, construct a product population instance gene network as M (figure.1). Each of these nodes v_i is a product gene, The connection between the nodes represent the relationship between the population gene product e_i , $e_i = (v_i, v_{i+1})$ is the reasoning relationship between nodes v_i and v_{i+1} .

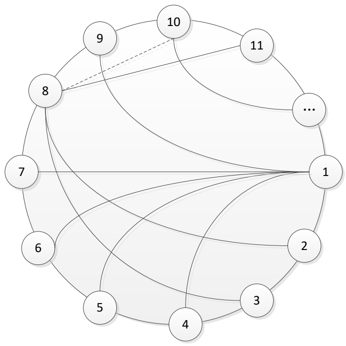

Figure 1. Product population example gene network M and node v_i

Group instance $D = \{d_i, d_2, ..., d_k\}$,a subgraph of the product instance gene network M related to the population instance D is $G_d = (V_d, V_{d_i})$,among them, v_{d_i} is any node in G_d , $e_{d_i}(v_{d_i}, v_{d_{i+1}})$ is any one side in G_d , represents the relationship between nodes v_{d_i} and $v_{d_{i+1}}$.

Step1. Set the product population reasoning gene set

Research and analysis using the experimental scale method, set up product population instances D ,analysis of several target product examples based on users, designers and engineers, obtaining population instances corresponding to several specific products according to weights, decomposition calculation to obtain the product inference gene corresponding to a specific product instance, construct a fuzzy instance gene set $Geneset = \{g_i, g_2, ..., g_m\}$.

Step2. Computation of neighbor sets in Inferential Gene Sets

For each g_i ,initialize $g_i = g_{i0}$,any side of $e_i = (v_i, v_{i+1})$ in M ,if $g_i = v_i$,then $G_i = G_i \bigcup \{v_{i+1}\}$;if $g_i = v_{i+1}$,then $G = G_i \bigcup \{v_i, v_{i+1}\}$,otherwise G_i keep unchanged, repeating calculations, until all edges in M have been checked.

Step3. Compute all gene sets for product instance D

Compute the gene collection v_d for example D :

$$v_d = Geneset \bigcup G_1 \bigcup G_2 \bigcup G_3 ... \bigcup G_n \tag{7}$$

Step4. Construction of a collection of related inference gene networks for product instance D

initialize $E_d = e_0$, for any edge in the product instance gene network graph M , $e_i = (v_i, v_{i+1})$, checking v_i and v_{i+1} does its belong to v_d at the same time, if both belong, then $E_d = E_d \bigcup (e_i)$; If not, then E_d is not change, repeated calculation, until all edges in M have been checked.

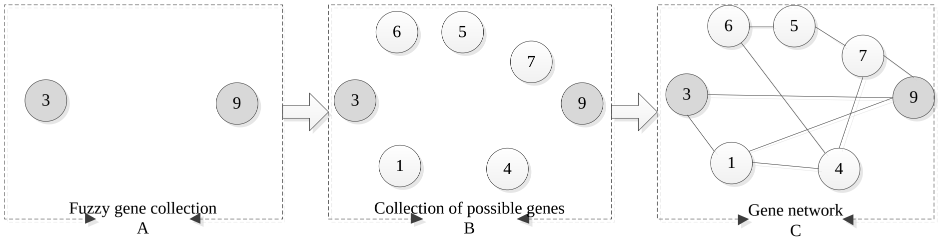

Figure 2. Example of gene network construction process

Product example gene network construction process(figure.2), where A is the fuzzy gene set $Geneset$ of the reasoning D that has been confirmed, contains product example genes 3 and 9,B reasoning D possible set of genes, C is the gene network for the final generated inference-related product examples c $G_d(V_d, E_d)$.

3.3 Product instance topology and optimization

Drawing on topological thinking of protein interaction networks in biology, perform inference-related product instance gene networks for topology analysis, mining highly important instance gene combinations, complete the combination of product instance genes, provide optimal solutions for subsequent detailed design, according to graph theory, each node in the product inference gene network is connected to several other nodes through wires, the number of nodes connected is the degree of this node, recorded as k_i, therefore, the degree distribution function in the network is written as $P(k)$:

$$P_k = \sum_{k'=k}^{\infty} P(k') \tag{8}$$

$P(k)$ is the probability when the degree of a random node is exactly K. If the cumulative degree distribution function conforms to a power-law distribution with a power exponent $\gamma - 1$, $P_k \infty \sum_{k'=k}^{\infty} \infty k^{-(\gamma-1)}$.

It means that the network constructed above is a scale-free network, Hub nodes that are relatively high in the network, such nodes are the target genes for inference. In the actual case design, the acquisition data of the target genome will be huge, need to combine the clustering coefficients in the network topology to optimize the target genes, the definition of clustering coefficient is as follows:

$$CC_i = \frac{3N_{\Delta}(i)}{N_3(i)} \tag{9}$$

$N_{\Delta}(i)$ represents the total number of triangles containing node i in the network, $N_3(i)$ represents the total number of triples containing node i in the network, expressed as follows:

$$N_{\Delta}(i) = \sum_{k>j} a_{ij} a_{jk} a_{ik} \quad N_3(i) = \sum_{k>j} a_{ij} a_{ik} \tag{10}$$

Among them, the clustering coefficient value range of C_i is [0,1], need to count the degree of nodes in the network and the value of CC_i, according to the value analysis, the inference target genome with the highest correlation of the instance can be determined, provide optimal solutions and auxiliary design information for engineering design.

Conclusion

Innovative design is an important method for the development of manufacturing. The article starts from the perspective of innovative design, based on reasoning logic, The key technologies of product population instance genes were studied. Constructed the definition and expression of product instance genes, based on complex network theory, established a product gene network model, and research on the product topology and optimization scheme. Through evolutionary reasoning algorithms, researched key technologies and models of case-based reasoning in product evolutionary design, will provide a new idea and method for innovative design.

Acknowledgements

Scientific Research Program Funded by Shaanxi Provincial Education Department (Program No. 19JK0832)

References

[1] Trousse, B. , & Visser, W. . (1993). Use of case-based reasoning techniques for intelligent computer-aided-design systems. International Conference on Systems. IEEE.

[2] Hsu, W. , & Woon, I. M. Y. . (1998). Current research in the conceptual design of mechanical products. Computer Aided Design, 30(5), 377-389.

[3] Pahl G, Beitz W . (1996). Engineering design.: A systematic approach. London: Springer.

[4] Chen, D. , & Burrell, P. . (2001). Case-based reasoning system and artificial neural networks: a review. Neural Computing & Applications, 10(3), 264-276.

[5] Tai Ligang, & Zhong Tingxiu. (2007). Product case population and product gene research. Journal of Shanghai Jiaotong University (09), 78-82.

[6] Teng Hongfei, & Zeng Wei et al. (2004). Evolutionary Design Methods and Applications. Journal of Mechanical Engineering (01), 5-10.

[7] Chen Jianguo, & Pan Yunhe. (2000). Research on creative design methods based on space exploration. Journal of Computer-Aided Design & Computer Graphics, 12 (6), 441-445.

[8] Goldenberg J, Mazursky D.(2002). Creativity in product innovation. Cambridge University Press.

[9] JOHN S.GERO. . Computational models of innovative and creative design processes. Technological Forecasting & Social Change, 64(2-3), 183-196.

[10] Carayannis, E. , & Coleman, J. . (2005). Creative system design methodologies: the case of complex technical systems. Technovation, 25(8), 0-840.

[11] Wang Chi. (2008). Research and application of key technologies of knowledge base system for rapid product design. (Doctoral dissertation, Chongqing University).

[12] Gao Changqing, Huang Kezheng, Zhao Fang, Ai Changsheng, & Cao Shukun. (2007). Research and Realization of Principles and Structure-based Rapid Innovative Design of Case-based Reasoning. China Mechanical Engineering (24), 12-18.

[13] Ding Lixin, Kang Lishan, Chen Yuping, & Li Yuanxiang. (1998). Advances in Evolutionary Computing Research. Journal of Wuhan University (Science Edition) (5), 561-568.