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GENE REGULATORY NETWORK MODEL FOR PRODUCT INDUSTRIAL DESIGN

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ABSTRACT

User's sensitive image to products is the emphasis that industrial design concerns, and is also the one of the key targets. Complicated mapping relations exist between design elements and user image, which make product's user image unpredictable. The paper tries to build a model to describe the mapping relations on the basis of graph theory, which introduces the concept of *genetic regulatory network* (GRN) into industrial design. The model takes design elements as nodes and the relationship between elements as edge to build and draw product's GRN graph. Through the GRN, product's design elements are classified and the types of nodes and nodes groups are recognized, as abstracted knowledge for designers to arrange their design activities, or prepare the searching strategy for automatic optimizing programs. An example of water bottle design is carried out to test GRN's aiding effect to product design.

Keywords: *Product Design, industrial Design, Genetic Regulatory Network, Product Gene*

1. INTRODUCTION

Product gene is the application of gene engineering thinking in product design. Gero [1], Rosenman [2] et al are the earliest person who use gene concepts to understand the product design, recently, P. Feng [3], X. G[4], S. Luo [5] and others has done a lot of research. In the early period, the study on gene products mainly concentrated in the field of mechanical design, the concern about users' perceptual imagery was increased recently, and the main research field is gradually transferred to the field of industrial design. According to the literature research, the current study about product gene mostly adopts genetic operation of the conventional crossover and mutation to cultivated varieties gradually after many generations of evolution .This way is inefficient and the primitive from the perspective of biological breeding, and the role of the designer is not highlighted, the design principle of technique mostly takes replacing the designer as the basic principles, and there is few auxiliary research was provided for the designers from the perspective of knowledge discovery.

Gene Regulatory Network （GRN) refers to the network formed by the interaction between intracellular genes [6], thorough understanding about the structure of GRN could precisely control the dominant characters through directly operating gene, the efficiency and accuracy are greatly improved compared with the traditional mode of natural selection. Although GRN is the research object of bioinformatics, its technical content belongs to data mining and knowledge discovery, many disciplines with algorithms as their major work are involved in, the research results also formed a great inspiration to other related fields which take biological algorithm theory as reference. At present, frequently-used GRN model includes the Boolean network model [6], linear combination model[6], Bayesian network model [7-8], principal component analysis model (PCA) [9], network motif model [10] and scale-free network model (BA model) [11] and others.

The present GRN model is mostly used for network structure discovery, in other words, looking for synergistic interactions between genes, finding the edges of GRN, connecting the gene nodes into a network, and identifying valuable subnets and key nodes from the structure characteristic of network. From the perspective of industrial design, these subnet or key nodes provide a macroscopic knowledge easy to understand for designers. Precise control on the perceptual imagery and other products' explicit traits through operating design elements is expected to be achieved through introducing GRN model into the field of product industrial design. This paper discusses the basic method of using GRN to assist the designer, and carry out a research on the assistant role of GRN in product design process through a design example.

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2. THE ESTABLISHMENT OF PRODUCTS GRN

Product GRN established is based on Graph theory. The GRN consists of nodes and edges connecting nodes, there are two main works constructing GRN products, namely design and edge node discovery. Application target of product GRN is to seek a set of node values through the network structure, allow the products have an optimal performance on external evaluation index (GRN output).

One of the key objectives of industrial design concerns is the users' perceptual image about product, so the research on product GRN in this paper defines the design goal as perceptual image of the product appearance can be decided by the users independently, the follow-up study was extended on such basis, looking for universal results, bring them into other sub goals of products design one by one, such as quality function, man-machine performance, innovation, technology, cost etc.

Product GRN node design is the construction of product gene, a set of parameters used express product completely, namely, the coding in optimizing algorithm based on evolutionary principle. According to the author, the research on product GRN should follow three basic principles for the construction of product gene, namely determinacy, operability and indivisibility.

Determinacy refers to the "expression level of product gene" is the product's intrinsic elements, it can be measured objectively, and it differs from man to man. Operability refers to the product gene values can be modified directly, in other words, it can be operated by designers, without having to go measuring and calculation through indirect means. Indivisibility refers to the gene is the smallest unit or standardized substructure constructing products, reconstruction is not needed in gene operations, which is also in line with the basic characteristics of biological gene.

In the above three principles, structure of product gene can be basically attributed to geometric morphological parameter, color, replaceable base part number, surface materials, materials and other explicit characterized visual features and physical character quantity. Gene expression of product scheme can be expressed as vector of each design parameter, namely coding.

There are two kinds of raw data for constructing products GRN. For the first category, it is all kinds of products already exist in the market, express them in accordance with the genetic design rules as standardized coding form, and with the use of statistical algorithm to identify each edge. The second category is more widely used in product innovation design, which is, using software technology randomly generate a large number of genes encoding, and building products program on such basis, allowing users to evaluate or select randomly generated program, and using high score program or the selected program as a raw material to identify the edges of GRN. The problem of less market product sample and lack of data can be solved by the latter; design optimization to the innovative product is an important method. This study is mainly based on the latter.

From the point of view of graph theory, the manifestation of product GRN is undirected graph, in which, the nodes represent genes, the edge between nodes represent the link between the two genes, namely, regulatory relationships, it can be said as coexpression while described the concept of biological networks.

After the product gene design is completed, the main task of constructing product GRN is to find the edge. In this paper, the Pearson correlation is used to find the edges between the nodes of the product gene, which is one of the common algorithms to build biological GRN [12].

Set a Pearson correlation coefficient a threshold value [r], when the r value exceeds the threshold value, then the two genes are related, an edge can be established between nodes represented by the two genes. Pairwise test about their relevance can be carried out for all gene nodes, finding all the edges, and establish the network of product gene GRN.

3. KNOWLEDGE PRECIPITATED FROM THE PRODUCT GRN

An important role of the product GRN is to assist the designers' innovation or optimization design, and therefore, its main function is precipitate macro knowledge can be understood and used by the designer directly. This paper is tend to precipitate two types of macro knowledge from the product GRN, that is the identification about the importance of the node (parameters) and the node group.

3.1 Identification About The Importance Of The Node

The significance of identification about the node importance is to tell the designer which nodes are the most important ones, which should be given the priority in processing. The importance of the node can be reflected from two aspects: first, the

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sensitivity, i.e. the changes in the value of node has a significant effect about the evaluation about the product, expressed by the sensitivity coefficient, i.e. whether the probability density curve of the node value shape has tendentiousness; The second is centrality, that is the number of nodes correlated with the nodes, in graph theory, that is the degree of the nodes. Identifications about the node importance varies from design objects depending on the particular condition.

The sensitivity is an important indicator for evaluating node; this paper adapts two ways to calculate node sensitivity depending on the sources of sample data.

First, divide the definition domain of each parameter is into m equitant intervals to represent m level of the parameters, if it is a symbol type parameter, and m represents the optional number of symbols of the parameters. If the sample source is anonymous (i.e. excluding evaluator information), the variance is used to characterize the size of sensitivity. If the sample source is attached with the information of the evaluator, F-test method can be used to carry out significance test about sample data with significance as sensitive indicators.

According to the two indicators, the threshold of the node degree and sensitivity, the nodes can be divided into four categories:

1) Critical nodes: nodes with high centrality and high sensitivity. The changes in the value of the critical node affect both the users' valuation and the values of the other nodes, so they are critical for product design.

2) Independent nodes: nodes with low centrality and high sensitivity. The low centrality is the main feature of the independent nodes, while they show high sensitivity, indicating that the node indicator is independent with the evaluation about product function, they have less coupling effect between the other nodes, in the design process, and they can be separated as independent variables.

3) Passive node: nodes with high centrality and low sensitivity. The changes in the value of the passive node has little effect on user evaluation, but this result may be due to the nodes affected by multiple other node at the same time (high centrality).

4) Secondary nodes: nodes low centrality and low sensitivity. The influence of secondary node on the evaluation about the indicators has small association with other nodes, indicating that the nodes are not important, which can be removed from the product gene.

3.2 Identification About The Node Groups

Node group is a collection of a number of elements in joint action. For designers, the meaning of node Group is: it requires taking into account the program parameters within the group while make modification, rather than modify only one of them.

There has a variety of methods for identifying GRN node Group, such as motif identification technologies referred to in the literature, or identify independent modules from GRN based on visual features. In this paper, two methods are considered to identify the node group: clustering coefficient method and correlation threshold method.

1) Clustering coefficient method

Clustering coefficient is a quantity used to measure the tightness of "social circle" (ie. the set of all nodes connected to the node) of a node defined by D. Watts, refers to the ratio of the actual number of connections between all nodes in the social circle with maximum theoretical number of connections. In addition to express the tightness of the node and adjacent points, cluster coefficient also reflects the nature of the node group. The nodes with cluster coefficient higher than a certain threshold and their social circle constitute nodes group. The concept of node group is similar to that gene groups with the relationship of co-expression, which acts as evaluation indicators (such as user imagery) of ensemble to the product.

2) Correlation threshold method

GRN presents clearly visualized group division characteristics by setting different correlation threshold. The connection strength between the nodes in the product GRN is a continuous variable, the presence or absence of the edge depends on the setting of correlation threshold, so under different thresholds, GRN edges show the differences in density. The number of node groups can be controlled by artificially setting the threshold size, and the importance levels of the node groups can be marked to facilitate the sequential processing of the designer.

4. APPLICATION CASE OF PRODUCT GRN

4.1 Case Description

The design of pure water bottle is used in this paper as an instance of object to catty out implementation and verification about the product GRN technology. Bottle container is an object carrier commonly used in product innovation experiment, for two reasons: first, the morphology of bottle-shaped rotary body can be expressed by a set of continuous real parameters to facilitate the

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construction of a continuous search space, which contribute to the comparability of the differences between the methods; second, the evaluation about bottle container appearance is completely based emotional imagery of evaluator excluding the interference of function, process, cost and other factors (a lot of research have done for these factors, and there are many research results, which will be not considered in this paper) . Innovation and optimization problems based on implicit perceptual goal haven’t achieved a good solution; it is the main concern of the GRN method.

The product object used in this paper is shown in Figure 1. Bottle container in the Figure uses 21 parameters to describe its shape completely, there are three types of parameter includes the transverse dimension (3), longitudinal dimension (13) and the corner arc degrees (5), the total height of the container and the outer diameter remains unchanged. Product form is simple, but it is not easy for the designer to handle 21 parameters. Therefore, it can be considered that the object has had the characteristics of the complex design tasks, and it is feasible to test the secondary effects of GRN

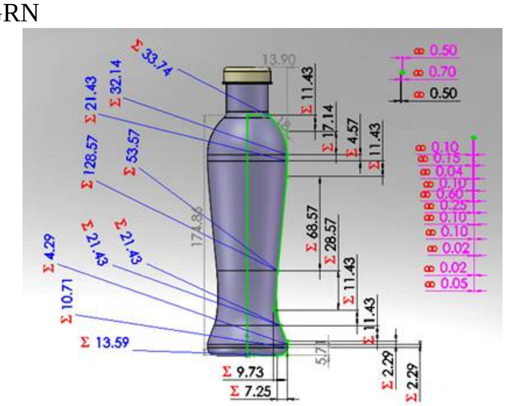

Figure 1: Definition Of Product Object

4.2 The Drawing Of Product GRN Graph

The above product model is defined parameterization software Solidworks, 21 parameters are defined as driven variable and stored in external Excel spreadsheet. Variables can change freely and generate a new configuration, the software automatically update model shape according to the new parameter configuration. The author has done three parts of programming work by using VBA tools for the case: first, random change generating new configuration of specified number for the 21 parameters in the Excel spreadsheet in the definition domain, show randomly generated new configuration to the user in parallel; allow the user to select the satisfied program and record the parameters in the program in another Excel spreadsheet; carry out analysis and processing about the parameters of the program selected by the user and draw GRN graph.

The above process is for the users and randomly searches their satisfaction program, the designers can manually operate software modification parameters to get designing program. 9 individuals were involved in experimental work and get 77 designing program through two ways (optional), as shown in Figure 2.

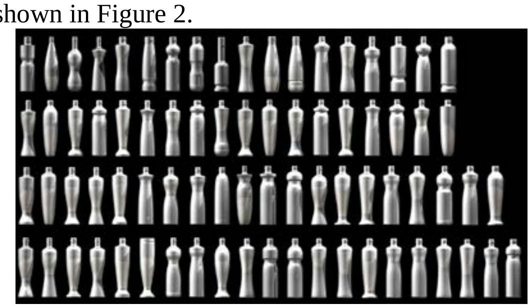

Figure 2: Program Plan Reached By Experiments

The sample data used in this paper has the information about the author, but because the number of samples contributed by each author is less, the calculation of sensitivity adopts the variance method. The parameter values are divided into 20 levels, product GRN shown in Figure 3 is obtained through data analysis.

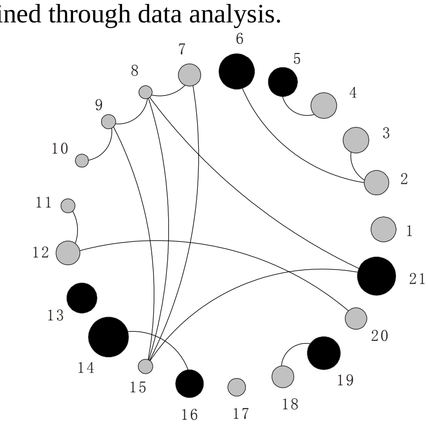

Figure 3: Product GRN Graph

In the figure, the node diameter indicates the parameters’ sensitivity value of the node, the line means the two nodes correlated, the case to take the correlation threshold [r] = 0.4.

4.3 The Importance Of The Node And The Identification Of Node Group

Set thresholds for sensitivity and node degree, the sensitivity threshold is 0.5 (solid black node in Figure 3 represents a sensitive node), the centrality threshold is 2 degree, (the degree of node greater than or equal to 2 is considered as the high centrality). The classification of 21 parameters nodes is shown in Table 1.

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Table 1: Node Classification

Node type	Nudes sum	Nodes number
Key nodes	1	21
Independent nodes	6	5、6、13、14、16、19
Passive nodes	6	2、7、8、9、12、15
Secondary node	8	1、3、4、10、11、17、18、20

GRN shown in Figure 3 shows a high degree of non-connecting characteristic under a certain degree of correlation threshold setting, 21 parameters constitute nine isolated sub graph. According to the correlation threshold method, it can be identified that the product GRN has six nodes groups, including the largest connecting domain consisted by 6 nodes, 5 small connecting domain with nodes of less than three and three independent nodes.

Follow macroscopic knowledge used for aided design can be drawn from GRN:

1) The only critical node is the bottom curvature, the two associated parameters are in the waist of the bottle; six nodes in the largest the connecting domain (node Group) contains 6 main parameters representing the form of waist and bottom, indicating there is a need for coordination design between the form of waist and bottom.

2) Two nodes representing the bottle bottom angle arc transverse and longitudinal (No.14,16) constitutes the node group, both of which are sensitive nodes, indicating that it has big impact on the user sensibility, proportional relationship between the two is relatively important. These two dimensions have no connection with bottom radian node (No.21), indicating that there is few connection between the size of the arc and the angle sharpness of arc, which can be designed independently.

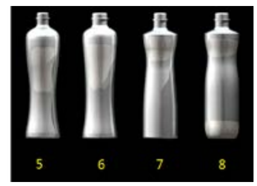
3) There is connection between the nodes representing the upper abdomen and waist radian (No. 18, 19), and the waist radian (19) is a sensitive node, it can be determined that there is echoe relationship between the two, a overall consideration need to be required.

4) There are more than one-third of the nodes belonging to the secondary nodes, a fixed value can be assigned to it depending specific circumstance to reduce the dimension of the solution space, simplify the goal need to be solved. Or carry out adjustment after the solving of other nodes.

The above analysis provides designers with the explicit knowledge available for operation, and basically coincides with common sense of shape perception. For the nodes need to be considered at the same time, further digging the functional relationship between the two by means of the encoding operation tool and gradual optimization can be made .

In order to test the auxiliary role of the knowledge precipitated by GRN in design, 9 experimenters are divided into two groups of auxiliary group and control group. Provide the analysis result of previous section to the auxiliary group, the design of control group will be carried out according to the original way. Design results are scored by the evaluation group and the results is shown in Figure 4:

a. auxiliary group



b control group

Figure 4: Auxiliary Group And Control Group

The average score of auxiliary group is 7.4, the average score of the control group is 6.5. The score of auxiliary group is slightly higher than the control group, and the convergence trend is relatively obvious, indicating that the assisting of the knowledge generates some positive impact on the design activities of the designers.

5. CONCLUSION

The principle of gene regulatory networks is a way to express the relationship between the complex elements, and it has certain value in describing the design elements of the products. Experimental studies have shown that expressing the complex relationships between the elements of the product design with the use of GRN is feasible; the network relationship between the elements of the product design is an objective reality. Products GRN can help to find the tacit knowledge of the user imagery, such as the relationship between the elements of the product design and its importance, and carry out formalization; it is able to provide a valuable assist for designers' innovation and automatic optimization.

A number of models in GRN research are used to describe the node relationship, such as a linear combination model, weighting matrix model, Bayesian network model, the application of these models will help to clarify the exact relationship between the design elements, further reduce the dimension about the design objects.

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REFERENCES

[1] J.S. Gero. Adaptive systems in designing: new analogies from genetics and developmental biology, *Adaptive Computing in Design and Manufacture*, Vol.12, No.3, 1998, pp.3-12

[2] M.A. Rosenman. An exploration into evolutionary models for non-routine design, *Artificial Intelligence in Engineering*, Vol.11, 1997, pp.287-293

[3] P. Feng, Y. Chen, S. Zhang. Product gene based conceptual design, *Chinese Journal of Mechanical Engineering*, Vol. 38, No.10, 2002, pp.1-6

[4] X. Gu, G. Qi. The Concept of the Gene Model of Process Information, *Chinese Mechanical Enginering*,Vol.9, No.11, 1998, pp.80-85

[5] S. Luo, S. Zhu, C. Feng. Product family design DNA in industrial design, *Chinese Journal of Mechanical Engineering*, Vol.44, No.7, 2004, pp.123-128

[6] Y. Lei, D. Shi, Y. Wang. Reviewing the Study of Gene Regulatory Networks from Bioinformatics, *Ziran Zazhi*, Vol.26, No.1, 2004, pp7-12

[7] N. Friedman. Inferring Cellular Networks Using Probabilistic Graphical Models, *Science*, Vol.303, No.5659, 2004, pp.799-805

[8] Covert, M.W., Knight, E.M., Reed, J.L., et al. Integrating High-throughput and Computational Data Elucidates Bacterial Networks, *Nature*, Vol.429, No.6987, 2004, pp.92-96

[9] C. Wang, N. Rao, Y. Wang. Principal Component Analysis for Exploring Gene Expression Patterns, *J.Biomed Eng.*,Vol.24, No.4, 2007, pp.736-741

[10] R. Milo., S. S. Shen-Orr, S. Itzkovitz, et al. Network motifs: Simplebuilding blocks of complex networks, *Science*, Vol.29, No.5594, 2002, pp.824- 827

[11] A. L. Barabasi, R. Albert. Emergence of scaling in random networks, *Science*, Vol.286, 1999, 509-512

[12] D. Yi, M. Yang, H. Li, M. Huang, W. Wang. The Construction of Gene Network by Correlation Analysis, *Chinese Journal of Health Statistics*, Vol.20, No.3, 2003, pp.144-146