Key Technologies of Population Genes in Product Design

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Abstract: Based on the theory and method of bioengineering, the article studies the gene of product instance population. The product instance population gene is defined, and the product instance population expression model is constructed, through the decomposition tree and population gene tree of the product instance, the population genes of the product instance are obtained and applied to product innovation design. Constructed product gene acquisition and expression methods help to standardize and repeat applications of design knowledge, improve product innovation design efficiency, combined with the example of the latch handle, the complete process of product design example genes is discussed.

1. Introduction

With the development of intelligent technology and computer-aided technology, the research of product innovation design has entered a whole new field. Intelligent innovative design becomes a new direction for product design[1], Case-based reasoning[2], design examples, and reuse of design knowledge have become important research directions and contents of intelligent CAD technology. In previous product designs, knowledge acquisition[3]and reuse[4]are the main bottlenecks that limit product innovation. But the technology of case-based reasoning[5], 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 be used to retrieve cases. The acquisition of design solutions requires manual intervention and intervention by design experts[6]. Based on the evolutionary algorithm, the method of product population gene design considering case-based reasoning provides the possibility for intelligent automation design of product innovation schemes[7]. The key elements to realize such technologies are to study the genes of the product instance population, classify the product design examples, establish the product instance population, extract the product design instance population genes, use the product instance population genes as the evolution conditions, and combine evolutionary reasoning technology.

2. Definition and expression

Biologically, population refers to the collection of all individuals of the same species in a certain time and space. This collection is not a mechanical collection, but the genetics of the population is passed to the offspring through mating. Population is the basic form of species existence and the basic unit of species evolution. The product instance population is defined as follows: the product instance population is a collection of product instances with the same basic functions, constituent units, and the same or similar characteristic attributes in a certain time and space.

The composition of a product includes design knowledge of the function, principle, and structure of the product. The evolutionary design method based on case-based reasoning needs to extract design knowledge from the product population, and then constitute the gene that determines the product traits. Therefore, a product instance population expression model needs to be established, is a design model of the constituent elements, relationships, and characteristic parameters that make up a product instance, a product instance model is a collection of product design knowledge, The product instance model is described as follows:

$$
\begin{aligned}
&Case(P_c) = Case(E_i) \\
&E_i = (F_i, P_i, R_i) \\
&F_i = (f_1, f_2, ..., f_l) \\
&P_i = (p_1, p_2, ..., p_m) \\
&R_i = (r_1, r_2, ..., r_n)
\end{aligned} \tag{1}
$$

In the formula, P_c is the product examples, E_i is the elements that make up the product instance, $i = 1, 2, ..., k$. F_i is the feature set of instance elements, P_i is the parameter collection, R_i is the collection of relationships.

The three-dimensional model of the product instance is represented as follows:

$$M_C = M_F \cup M_P \cup M_S \tag{2}$$

In the formula, M_C is the product instance model, M_F is the functional view model, M_P is schematic view model, M_S is the structural view model.

3. Product population gene definition and acquisition

Innovative design has similar characteristics to biological genetic evolution, most product innovations are reuses of existing principles and other design knowledge. The product gene exists in the product itself and is a key node in the design of product evolution, from the product instance population, the gene of the product population can be extracted and applied to the innovative design of the product[8]. In biology, the carrier of genetic information is called deoxyribonucleic acid (DNA) organisms, gene fragments in different parts determine certain functional traits of the organism[9], in NDA, the four base codes A, G, C, and T make up the biological genetic gene[10], drawing on biological principles, the three basic elements of the product's functional characteristics, principle effect, and structural form can be defined as product genetic elements. The detailed description is as follows:

- A functional gene is a basic information unit that describes the function and characteristics of a product.
- The principle gene is the basic information unit describing the principle and physical effect of the product.
- A structural gene is a basic unit of information that describes the relevant structure and material properties of a product.

The specific condition for the existence of any product is that the product's functional genes, principle genes and structural genes are determined at the same time, a single gene cannot constitute and describe a product. Product genes determine product traits, provide innovative solutions for product populations through the inheritance, mutation and evolution of product genes.

In biological engineering, biological genes are made up of biological genes by reverse transcription[11]. The acquisition of product genes also requires a reverse transcription process on the product instance population. By known biological proteins, genetic composition of biological heritage through reverse translation, biological genes are obtained through the reverse transcription process. Drawing on the biological reverse transcription process, fast and reliable access to product instance genes, through the analysis of example products, get the original understanding of the product instance (the principle of solution), contains functional, principle, and structural information, the reverse transcription process is performed to obtain the product gene.

3.1 Product example gene expression

After obtaining the product instance gene, need to encode the product instance gene[12], according to the product instance hierarchical decomposition tree model established above, the product example tree is expressed using the product gene tree.

The product example genes are represented as follows:

$$G_C = tree(G_{N,i}) \tag{3}$$

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

$$G_{N,i} = f(F_{GB,i}, S_{GB,i}, P_{GB,i}) \tag{4}$$

In the formula, $F_{GB,i}$ 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 nodes, expressed as follows:

$$\begin{cases} F_{GB,i} = (A_{gf}, C_{gf}, M_{gf}, I_{gf}) \\ S_{GB,i} = (A_{gs}, C_{gs}, M_{gs}, I_{gs}) \\ P_{GB,i} = (A_{gp}, C_{gp}, M_{gp}, I_{gp}) \end{cases} \tag{5}$$

In the formula, 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 Evolutionary design of genes

The obtained offspring population is generally better than the previous generation, can effectively remove the defects of the previous generation, it is an innovative design method. The evolutionary design method based on the product instance population gene can carry out various evolutionary design methods. When optimizing the design, it is only necessary to change the genetic molecules that need to overcome the defects of the existing product, such as the functional genes and principle genes unchanged, and only the structural gene evolution design. When innovative design is needed, the evolutionary design of functional genes and principle genes requires new physical principles and new product functions, similarly, genes can be designed to cross between different populations.

Previous single-objective optimization algorithms often cannot solve multi-objective optimization problems, the general approach is to convert a multi-objective problem into a single-objective problem, the specific expression using linear weighting method is as follows:

$$\min \varphi = \sum_{i=1}^{m} \alpha_i f_i(x) \tag{6}$$

$s.t. x \in \Delta$, Δ is a feasible solution set.

In the formula, α_i is the weight coefficient of each goal, satisfied with $\sum_{i=1}^{M} \alpha_i = 1$.

According to different design goals, set specific evolution methods, parametric design of the structure, or choose structural evolution when structural innovation is needed, need to find new principles of action, choose the way of principle evolution when performing principled innovation design, need to combine functions or find new functions, and choose a function evolution method when designing a function.In the actual evolution process, a single level, multiple levels or any level of evolution can be choose. When setting the evolution level, it should be noted that if it is a single population evolution or multiple population evolution, the traits of the evolutionary individual instance gene tree corresponding to nodes at all levels are basically the same,

3.3 Product evolution design process

The innovative design of complex product solutions through evolutionary methods has its own characteristics, which is very different from the usual evolutionary optimization. The previous analysis of the product solution evolutionary design through the product instance population. The process model of product solution evolution design through product instance population is given below.

(1) Enter design requirements, analysis functions, and feature requirements.

(2) Formatting requires data, conforms to the expression of product instances, matches evolution rules, and extracts product instances.

(3) Refer to the evolution rules to determine the evolution method.

(4) Select the corresponding product instance population from the product instance library.

(5) The product gene corresponding to the product instance population is selected to generate an evolutionary population.

(6) A genetic algorithm is selected to establish a fitness function.

(7) Enter the loop evolution operation: the individual evaluates, and if the termination condition is met, the optimal solution is output; if the termination condition is not met, the operation of crossover, and the individual evaluation is performed again, and the cycle is repeated until the termination is satisfied condition.

(8) The optimal solution is stored as a new product instance in the product instance library and the product gene library.

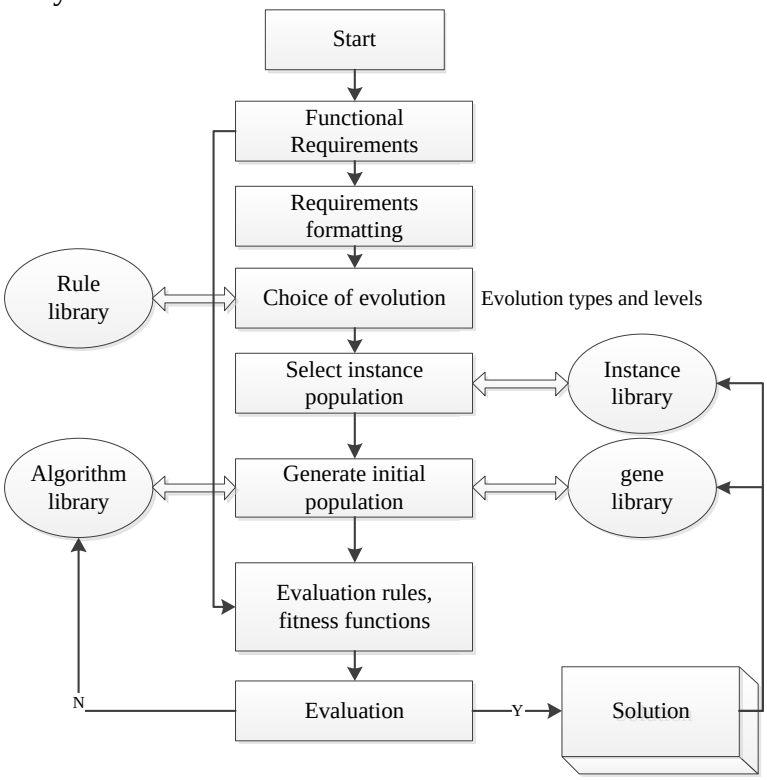

Figure 1. Flow chart of evolutionary design

Conclusion

Extraction of product instance population genes is conducive to the standardization, inheritance, accumulation and reuse of product design knowledge, the article is oriented towards product innovation design, combining key technologies in evolutionary design methods, the definition, acquisition and expression of design knowledge (product genes), combining bioengineering theories and ideas, the product example population genes are discussed in detail. Researched the key technology of product example gene definition, acquisition and expression, put forward a product design knowledge model, research product case trees and product gene trees, obtain product genes and perform product gene expression, build process models for product evolutionary design. The extraction of population genes of product examples is conducive to the standardization, inheritance, accumulation and reuse of product design knowledge, and modern product design intelligent, integrated and automated development complement each other. In the following, the evolutionary design optimization algorithm will be studied in combination with specific product design examples.

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