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Application of case modification based on genetic algorithm in the complex mechanical product

Yulan Hu and Yang Song

School of Information Science and Engineering, Shenyang Ligong University, Shenyang, China

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ABSTRACT

Because of case diversity and being difficult to get field knowledge in the case modification process, case modification becomes a key technique in case-based reasoning (CBR). According to the above-mentioned problems, taking advantage of the characteristics of genetic algorithm, genetic algorithm can be applied in the case modification. To find the optimal solution with the least delay possible, the similar cases in the case base are used as the initial population of genetic algorithm; The grey correlation calculation formula is the objective function, which can make the scheme that has the maximum similarity with the design problem continue to participate in the operation; Linear crossover operation and non-uniform mutation operation are chosen to avoid premature convergence of genetic algorithm; At last, take numerical control machine tool spindle as an example, MATLAB program is written to calculate the optimal design scheme according to the above ideas. Case study results show that this algorithm is a scientific and practical method.

Keywords: Complex products case modification; genetic algorithm; case-based reasoning (CBR)

INTRODUCTION

The meaning of Case-based reasoning (CBR) is as follows: At first, we need to have the developed successful cases in case base. Then, according to the characteristics and requirements of the design product, the similarity would be found between the design product and cases in the case base. At last, the case that has the highest similarity would be modified, after modification, the case become the new scheme that can solve the current problem and is saved to the case base[1]. CBR is mainly composed of case base establishment, case retrieval and case modification. At present, case base establishment and case retrieval have produced some relatively mature algorithms. Case modification generally involves case parameter change, different cases need different modification methods, and so case modification becomes CBR's key technique. There are four main methods aiming at case parameter change. The first one is model-based reasoning, its basic principle is that each case has a structure-property-function model associated with it, the model is used to guide the old case to modify to meet the different requirements of the new design product; The second is constraint satisfaction strategy, the method is that case evaluation constraints are defined in advance, the design requirements are summarized and expressed in the form of constraint; The third modified technique is based on genetic algorithm, using the extracted cases, a new set of cases can be got through the crossover operator and the mutation operator, and then modified cases are obtained by constraint checking and calculation of fitness; The fourth one is based on rules reasoning, it relies on the case adjusting rule, compares the current design requirements with the similar case by retrieving from the case base. Modification strategy or process can be proposed according to the past experience[2]. Because of complex mechanical product with multiple attributes, multi-hierarchy and complexity, which make it difficult to get case rules and constraints, the expected purpose can not be achieved. The characteristics of genetic algorithm make it very suitable for case modification. Therefore, this article applies genetic algorithm to complex mechanical product case modification process, and illustrates its feasibility and effectiveness through an example.

Method of Genetic Algorithm

1.1 Case Parameters Estimation

1.1.1 Case Description

Axiomatic design is a kind of design on the basis of domain and design theory , the main purpose is to establish a design scientific and normative, and to provide scientific theoretical basis for designers to improve the design.

There are 11 CNC machine tool spindle cases in the case base, each case has five feature attributes. The expression form of each case is shown as follows:

Table 1 The expression form of case in the case base

Case Number	Case Name	Rotation Precision (mm)	Rotate Speed (r/min)	Power (kw)	Average Diameter (mm)	Bore Diameter (mm)
i	X_i	$x_i(1)$	$x_i(2)$	$x_i(3)$	$x_i(4)$	$x_i(5)$

So the feature attribute vector of the case X_i is as shown below:

$$X_i = (x_i(1), x_i(2), x_i(3), x_i(4), x_i(5))^T \tag{1}$$

The case feature attribute matrix X can be made up of the case feature attribute vector in the case base.

$$X = (X_1, X_2, \cdots, X_{11}) = \begin{bmatrix} x_1(1) & \cdots & x_{11}(1) \\ \vdots & \ddots & \vdots \\ x_1(5) & \cdots & x_{11}(5) \end{bmatrix} \tag{2}$$

Among them, $X_i = (x_i(1), x_i(2), x_i(3), x_i(4), x_i(5))^T$, X_i represents the case which case number is i, $x_i(k)$ says the value of the attribute k of case X_i .

1.1.2 Coding method

The gene is coded by real number coding, each gene in the chromosome only corresponds to one feature attribute, which is convenient to calculate behind and makes the results more accurate. Corresponding relationship is as shown in table 2 [3].

Table 2 Corresponding relationship between the feature attribute vector and genes in chromosome

X_i	$x_1(k)$	$x_2(k)$	$x_3(k)$	$x_4(k)$	$x_5(k)$
Chromosome	gene1	gene2	gene3	gene4	gene5

1.1.3 Initial Population

Because of initial population that is generated randomly in the feasible region is likely to lead to premature convergence of genetic algorithm, to avoid that, five similar cases that are selected from the case base make up the initial population, which ensures the initial population within the feasible region, and is helpful to find the optimum solution of genetic algorithm [4].

1.1.4 Objective Function

Because case modification in CBR is based on case retrieval in CBR, the purpose of case retrieval is to find the similar case, case modification is to modify the similar case, which makes the result close to the design problem and accord with the requirement of design problem. In this paper, the formula of grey correlation degree in grey relational analysis theory is objective function of genetic algorithm, high similarity individual that has the maximum adaptive value can continue to participate in the genetic operation, and finally we can get the optimal design scheme [5-6].

The steps involved in the grey correlation degree analysis are as follows [7]:

Step 1 Determine the reference sequence and comparative sequence.

In this paper, problem feature attribute vector X_0 is reference sequence, case feature attribute matrix X is comparative sequence.

Step 2 Normalization
Different value of case feature attribute has different dimension, and each value has the order of magnitude difference that we can see from X_0 = (0.004 2400 37 230 76) that is the design problem vector. In order to calculate conveniently later, we need to normalize the data. The rotation accuracy, for example, is normalized, take 0.001* mm as the unit, then $X_0(1)$=4. The other feature attribute is in the same way to be normalized, so different feature attribute in the vector has the same order of magnitude through reasonable selection of dimension. After normalization, X_0 = (4 2.4 3.7 2.3 7.6). The normalization rule of the individuals in population is the similar treatment [8].

Step 3 Calculate the correlation coefficient.

$$r(x_0(k), x_i(k)) = \frac{\min\limits_i \min\limits_k |x_0(k) - x_i(k)| + \rho \max\limits_i \max\limits_k |x_0(k) - x_i(k)|}{|x_0(k) - x_i(k)| + \rho \max\limits_i \max\limits_k |x_0(k) - x_i(k)|} \tag{3}$$

In the formula 3, $\rho \in (0,1)$ is resolution ratio, here $\rho = 0.5$.

Step 4 Calculate the correlation.

$$r(x_0, x_i) = \sum_{k=1}^{5} \omega_k r(x_0(k), x_i(k)) \tag{4}$$

ω_k is the weight of the attribute k, $0 \le \omega_k \le 1$, $\sum_{k=1}^{5} \omega_k = 1$. We calculate the weight vector ω = [0.3695 0.1391 0.2133 0.1235 0.1546] by variation coefficient method [9].

The objective function is defined as:

$$f(x) = \max r(x_0, x_i) \tag{5}$$

1.2 Genetic Operation

1.2.1 Selection Operation

Adopt Roulette Wheel Selection here [10].

$$P_{x_i} = f_{x_i} \Big/ \sum_{i=1}^{n} f_{x_i} \tag{6}$$

Where let f_{x_i} be the fitness of case X_i, P_{x_i} is the selected probability of case X_i.

1.2.2 Crossover Operation

Crossover operation is not only to produce new individuals, but also to expand the searching scope, so crossover operation is very important to evolve the individuals. In order to get a better population offspring, we introduce linear crossover operator [11].

Take 2 parent bodies $X_i = (x_i(1), x_i(2), \cdots, x_i(5))$ and $X_j = (x_j(1), x_j(2), \cdots, x_j(5))$ participate in crossover. We can get 3 individuals $X'_m = (x'_m(1), x'_m(2), \cdots, x'_m(5))$ m=1,2,3 by computing the following formula .

$$x_1'(k) = \frac{1}{2}x_i(k) + \frac{1}{2}x_j(k) \tag{7}$$

$$x_2'(k) = \frac{3}{2}x_i(k) - \frac{1}{2}x_j(k) \tag{8}$$

$$x_3'(k) = -\frac{1}{2}x_i(k) + \frac{3}{2}x_j(k) \tag{9}$$

Calculate fitness value of the individuals that we get through the above calculation, choose two individuals that have higher fitness value, so use the two individuals as the offspring.

1.2.3 Mutation Operation

Mutation Operation can ensure the diversity of the population, so which mutation operation method is applied is very important. According to the characteristics of complex mechanical products, we adopt non-uniform mutation operation here [12].

The method is as follows:
At first, function $\Delta(t, y)$ can be defined as:

$$\Delta(t, y) = y[1 - r^{(1-t/T)^b}] \tag{10}$$

In the formula 10, r is uniformly distributed random number in [0,1]; T is the largest evolution algebra; b is a parameter that determines the non-uniform degree, b=6 here.

And, if case X_i mutates, then after mutation, $x_i'(k)$ is:

$$x_i'(k) = \begin{cases} x_i(k) + \Delta(t, U_B - x_i(k)) & round(rand) = 0 \\ x_i(k) - \Delta(t, x_i(k) - L_B) & round(rand) = 1 \end{cases} \tag{11}$$

$round(rand)$ means random numbers that is between 0~1 round to the nearest integer; L_B is the lower bound of variable $x_i(k)$ and U_B is the upper bound of variable $x_i(k)$, t is evolution algebra.

From the formula 10 and 11, we can see that if evolution algebra t increases, then $\Delta(t, y)$ is decreasing monotone, and ultimately tends to zero, so it is within the interval [0,y]. That means global search at the beginning stage of the algorithm, and local search at the later stage of the algorithm.

Case Modification Steps Based On Genetic Algorithm

From what has been discussed above, we can conclude case modification steps based on genetic algorithm:

Step 1 Initialization. Determine the initial population size M, crossover probability P_c, mutation probability P_m, the largest evolution algebra T.

Step 2 Calculate the fitness of the individuals in a population.
Step 3 Selection, crossover, mutation operation on population.
Step 4 Judge termination conditions. If t<T, then t=t+1, go to (2); If t>T, we use the largest fitness of individuals in the evolutionary as the optimal solution of the output, then terminate the algorithm.

Case Study

In the case study of NC machine tool spindle, the design problem vector X_0 = (0.004 2400 37 230 76). The five cases in the case base which are similar with the design problem make up the initial population of genetic algorithm. Crossover probability P_m =1, that is all the selected individuals in population participate in the crossover operation. Mutation probability P_c =0.1, genetic algebra T=100.

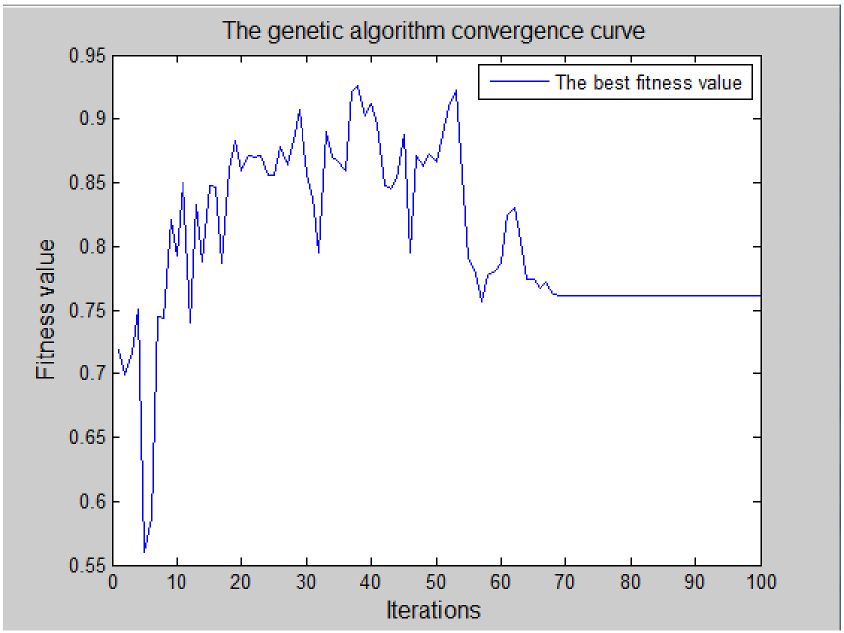

Figure 1 The genetic algorithm convergence curve

Write the MATLAB program to achieve the algorithm in this article.

After calculation, the similarity between the initial population and the design problem is as shown below.

$\gamma(x_0, x_1)$=0.7194 $\gamma(x_0, x_2)$=0.6614

$\gamma(x_0, x_3)$=0.5970 $\gamma(x_0, x_4)$=0.5468 $\gamma(x_0, x_5)$=0.4394

After calculation, the best fitness value in every generation form figure 1. The individual x that has the similarity of 0.9257 with the design problem can be got in the 38th generation, x= (4.0092 2.2081 3.7401 1.9267 7.6045). At last, we should convert individual value into case feature attribute dimension, so the scheme value is that x= (0.004 2208 37 193 76).

CONCLUSION

In this article, aiming at the complexity of case modification, we put forward to modify the case by using genetic algorithm. This paper presents the fitness function selection method, method of determining the initial population and design method of genetic operator, this kind of algorithm has been applied in the complex mechanical products, and we can obtain the expected results. The method introduced in this paper improves the modification of complex mechanical product similar case, reduces the similar case modification difficulty, overcomes the difficulties that modified rules in the professional field are difficult to be got, provides the reference for the case modification, and improves the efficiency of complex mechanical product design in case-based reasoning.

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