Research on cloud forging resource service selection optimization based on genetic algorithm

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Abstract. As a concrete manifestation of “manufacturing as service”, cloud forging is a cross-integrated product of advanced manufacturing, information and emerging Internet of Things technology. To make full use of the manufacturing resources of cloud forging, it is of great importance to optimize the resource selection before scheduling. This research proposes a cloud forging resource service optimization strategy based on genetic algorithm. Taking into account the characteristics of cloud forging resource service optimization, sharing cost, interaction time, and service quality are selected as the three preferred indexes of cloud forging resource service, and these three indexes are quantified. The genetic algorithm is used to solve the cloud forging resource service optimization model, and the cloud forging resource service with the best performance is selected. Finally, an example is used to verify the effectiveness of the proposed method.

1. Introduction

With the "Industry 4.0" revolution, the economic and technological patterns of all countries in the world are undergoing rapid changes and developments [1]. The United States proposed the "Industrial Internet", and China proposed "Made in China 2025" and "Internet +" and others [2]. The global market competition is unprecedentedly fierce, and new production models and operating services have kept companies in an environment that changes on demand. Cloud Forging is also a cross-integrated product of advanced manufacturing technology, information technology and emerging Internet of Things technology, which is a concrete manifestation of “manufacturing as service”. It uses the network to unify the resources related to the product life cycle to form a forging resource pool, which is managed and scheduled by the cloud forging platform to provide users with various cloud forging services that can be used on demand. Compared with other networked manufacturing, cloud forging embodies the idea of centralized use of decentralized resources and capabilities, that is, it not only provides enterprises with a platform for resource sharing, but also realizes collaborative manufacturing of complex tasks.

In terms of cloud manufacturing resource service optimization technology, many scholars at home and abroad have conducted in-depth research. According to the characteristics of the optimization problem in the new product development process, Yin Chao etc. proposed an optimization system for eight variables, and analyzed the optimization process using the gray correlation analysis method [3]; Cai Tan etc. proposed an alternative manufacturing cloud service optimization problem and designing...
a solution method. For quantifiable service quality characteristics, comprehensive weighting is used for the unquantifiable characteristics of service quality, the intuitionistic fuzzy set algorithm was used to analyze [4]; Li Yiming considered the service combination optimization problem in the two cases of a single task request and multiple task requests, and analyzed the service combination the detailed process and the use of cross-mutation particle swarm algorithm to solve this problem [5]; Fu Chao etc. used evidence-based reasoning to screen cloud services, and established a mathematical model with cost, time, and quality as optimization indicators. The services are selected from a centralized service for combination [6].

In order to objectively, comprehensively and efficiently realize the optimization of cloud forging resources on the cloud forging service platform, this research proposes a cloud forging resource service optimization strategy based on genetic algorithm. Taking into account the characteristics of cloud forging resource service optimization, sharing cost, interaction time, and service quality are selected as cloud forging resource service indexes. The genetic algorithm is used to solve the cloud forging resource service optimization model, and the cloud forging resource service with the best performance is selected. Finally, an example is used to verify the effectiveness of the above method.

2. Analysis and modeling of cloud Forging service optimization selection

2.1. Problem description

With the continuous improvement of the requirements of cloud service providers, the factors to be considered in the selection of cloud forging resource service are becoming more and more complex. The optimization problem can be described as follows: for example, suppose that a complex cloud forging service needs to be completed jointly by m subservices, and the candidate resource services of the i subservice have \( p_i \) to choose from, so \( S_i = \{s_{i1}^j, s_{i2}^j, \cdots, s_{ip_i}^j\} \), where, \( s_{ij}^j \) represents the j candidate service of the i cloud forging service, \( s_{ij}^j = [C_i^j, Q_i^j, T_i^j] \) which represent shared cost, quality, and time, \( i = 1, 2, \cdots, m; j = 1, 2, \cdots, p_i \). Therefore, the number of combinations selected for cloud forging service is \( \prod_{i=1}^{m} 2^{p_i} \). This study considers that the optimization choice of cloud forging service is a multi-objective combinational optimization problem. The purpose of this study is to optimize and select the most reasonable group from the mass cloud forging service combination.

This requires a scientific evaluation of the combination of quantitative indicators described above one by one. In the cloud forging service platform, shared cost, quality and interaction time are key reference indicators in the selection of cloud forging service. Therefore, in order to optimize cloud forging resource service with high satisfaction, the following conditions should be met.

Total cost shared by cloud forging service C: This index is the key index considered by cloud users when choosing cloud forging service. It consists of forging cost C1, machining cost C2, heat treatment cost C3, inspection cost C4 and other cost C5.

\[
C = \sum_{i=1}^{5} C_i
\]

The lower the cost value, the better. To minimize the total cost of cloud forging service sharing, its objective function is expressed as follows:

\[
\text{obj}(C) = \sum_{i=1}^{5} C_i = C_1 + C_2 + C_3 + C_4 + C_5
\]  

(1)

Cloud forging Service Quality Q: Quality Q is another important index in the optimization process of cloud forging service resources, which is composed of reliability Q1, credibility Q2 and availability Q3.

Cloud forging service Quality Q is a qualitative attribute index, for which the corresponding attribute index value can be obtained by the evaluation expert scoring method. The evaluation grades of the qualitative indicators are divided into very poor, poor, poor, general, good, good, and very good.
In order to be consistent with the cost and time, the smaller the quality attribute index value is, the better the quality is. The corresponding score values of these seven evaluation grades are 7, 6, 5, 4, 3, 2, 1 respectively. M experts were set to score the quality attribute index, and each expert assigned corresponding weight. The index value $Q_i$ ($i=1,2,3$) of the quality attribute index could be obtained by weighting and summing the score value of each quality attribute index of each expert. To make cloud forging service quality the best, if there are N sub-cloud forging tasks, each weight is represented as $w_{Qj}$ and its objective function is expressed as follows:

$$\text{obj}(Q_i) = \sum_{j=1}^{M} w_{Qj} Q_i, i = 1, 2, 3$$

(2)

Cloud Forging service Interaction time T: The cloud forging service platform requires the cloud forging service provider not only to complete the tasks of the cloud service requester as required, but also to timely feedback the completion results to the cloud forging service requester within the required time, striving to achieve the shortest interaction time on the premise of completing the tasks. The interaction time of cloud forging service includes four parts, namely, forging completion time $T_1$, machining completion time $T_2$, heat treatment completion time $T_3$, and other time $T_4$.

2.2. Mathematical model

The multi-objective optimization selection model of cloud forging resource service is:

$$G(x) = \min[g_1(x), g_2(x), \ldots, g_n(x)] \quad \text{s.t.} \quad f(x) \geq 0$$

(3)

Where, $f(x)$ is a constraint function; $g(x)$ is the target function. The optimization of cloud forging resource service must ensure the effectiveness of cloud forging service. Therefore, the dynamic composition of cloud forging services needs to satisfy the following objective function.

(1) Define variables

$$\theta_i^j = \begin{cases} 1 & \text{Choose } s_i^j \\ 0 & \text{Otherwise} \end{cases}$$

Where, $s_i^j$ represents cloud forging resource service $i$ and the candidate cloud forging service $j$ is responsible for it, $j=1, 2, \ldots, m$.

(2) Define the objective function $\text{obj}$. The optimization objectives of this study are shared cost $C$, quality $Q$ and interaction time $T$. According to the above problem description, the objective functions of the three are taken as the objective functions to realize the optimization selection of cloud forging resource service.

a. Cloud forging service platform the total cost of cloud service sharing $C$ is the lowest $\min C$ in the selection process of cloud forging resource service.

$$\min(\text{obj}_1) = \sum_{j=1}^{n} \sum_{i=1}^{m} C_i^j / \theta_i^j$$

(4)

b. Cloud forging service platform Cloud forging resource service selection process cloud service quality $Q$ best $\min Q$.

$$\min(\text{obj}_2) = \sum_{j=1}^{n} \sum_{i=1}^{m} Q_i^j / \theta_i^j$$

(5)

c. Cloud service interaction time $T$ is the shortest in the selection of cloud forging resource service.

$$\min(\text{obj}_3) = \sum_{j=1}^{n} \sum_{i=1}^{m} T_i^j / \theta_i^j$$

(6)

(3) Solution of optimal model
In this study, the multi-objective optimization problem of cloud forging resource service selection is transformed into the following single-objective optimization function, whose expression is as follows:

$$\min g(x) = w_1C + w_2Q + w_3T$$

(7)

Where: $w_k$, $k=1,2,3$ are the constituent weights of each indicator respectively, and $\sum_{k=1}^{3}w_k = 1$. Because the dimensions of the three attribute indexes are different, it is necessary to standardize the above three indexes. $C$, $Q$, $T$ are the property index values after standardized processing.

(4) Constraints

Each cloud forging resource service request should select at least one candidate cloud service.

3. Optimization of cloud forging service based on genetic algorithm

Considering the characteristics of cloud forging service selection and combination under cloud forging service platform, genetic algorithm is adopted in this study to realize this optimization problem. The specific selection process is as follows:

(1) Coding

The genetic algorithm for cloud forging service selection in the cloud forging resource service platform adopts binary coding form, as shown in Figure 1. Each candidate cloud forging resource service is represented by a field, each field has two values of 0 and 1, $H_j^i = 0$ means that the $J$th candidate cloud forging resource service $s_j^i$ of the $i$ cloud forging resource service request is not selected, otherwise it is selected. The total number of candidate cloud forging resource services determines the length of the binary code.

![Figure 1. Encoding mode.](image)

(2) Generate the initial population

The size of the group determines the size of the search space. According to the size of the optimization problem of cloud forging resource service, the initial group size $N=10$ is randomly generated. Before birth, each individual should judge whether it meets the constraint condition $\sum_{j=1}^{J}H_j^i = m_i(m_i \geq 1)$. This individual is valid when $m_i$ is equal to the number of cloud forging services required for the $i$ subtask. If the conditions are not met, the individual cannot be produced. Otherwise, the individual is born until the $N=10$ condition is satisfied. For the birth of the $j$ candidate cloud forging resource service (such as heat treatment service), the calculation formula is as follows:

$$s_j = round(rand)$$

(8)

$$s_j = round((1 - \sum_{i=1}^{J}x_i) \times rand)$$

Where, the function $round()$ is for integer; $rand$ Represents a random number between [0,1].
(3) Calculate fitness

Fitness function is the basis of evolutionary search [7], When the data is standardized and unified to the interval [0, 1], the fitness function is constructed as:

$$f(t) = g(t) = w_c \times C(t) + w_r \times T(t) + w_q \times Q(t),$$

where $t$ is the number of iterations. In the genetic process of a population, the fittest survive and inherit the next generation. Therefore, this study makes appropriate modifications to the fitness function, and the expression is as follows:

$$f(t) = c - (w_c \times C(t) + w_r \times T(t) + w_q \times Q(t))$$

(9)

Where, $C$ is a constant value greater than 3.

Combined with the objective optimization function, we get:

$$\max(f(t)) = c - (w_c \times \min(C(t)) + w_r \times \min(T(t)) + w_q \times \max(Q(t))))$$

$$= c - (w_c \times \text{obj}(C,t) + w_r \times \text{obj}(T,t) + w_q \times \text{obj}(Q,t))$$

$$= w_c \times (c - \text{obj}(C,t)) + w_r \times (c - \text{obj}(T,t)) + w_q \times (c - \text{obj}(Q,t))$$

(10)

Where, $\text{obj}(C,t), \text{obj}(T,t), \text{obj}(Q,t)$ Represents the value of the target function inherited to the generation $t$ population. If the $\text{value}(C,t) = c - \text{obj}(C,t)$, $\text{value}(T,t) = c - \text{obj}(T,t)$, $\text{value}(Q,t) = c - \text{obj}(Q,t)$, then the maximum fitness expression is as follows:

$$\max(f(t)) = w_c \times \text{value}(C,t) + w_r \times \text{value}(T,t) + w_q \times \text{value}(Q,t)$$

(11)

Where, $\text{value}(C,t), \text{value}(T,t), \text{value}(Q,t)$ Is the target fitness inherited by the population to generation $t$.

(4) Choosing

Considering that the best cloud forging resource service is best inherited to the new population, this study adopts the combination of optimal retention strategy and roulette. Suppose the fitness of a single individual is $f_i (i = 1, 2, \cdots, L)$, and the fitness of the whole population is $\sum_{i=1}^{L} f_i$, then the probability of the $i$ individual being selected is expressed as $f_i = \frac{f_i}{\sum_{i=1}^{L} f_i}$. If $f_{i-1} \leq \text{rand} \leq f_i$, then the $i$ individual is selected. The optimal retention strategy is to replace the individual with the highest fitness in the new population of generation $I$ after the genetic operation, and the remaining individuals do not participate in the operation, forming the next generation population. In this way, the number of excellent gene individuals in the process of population genetic evolution gradually increases.

(5) Crossover and mutation

Aiming at the optimization problem of cloud forging resource service, this study adopts the strategy of single point crossover to produce the next generation. New generations of individuals cross over and then single-field variation. The intersection point and the variation point are randomly generated. The crossover probability is generally 0.6~1.0, and the variation probability ranges from 0.001~1.0.

(6) Termination conditions

Repeat steps (1) ~ (5) above until 1 is equal to the set maximum number of iterations, and stop iteration.

4. Optimization calculation

Using the above optimization strategy of cloud forging resource service based on rough set theory and genetic algorithm, this study takes a forging company to issue a forging cloud service request through the cloud forging service platform for cloud service optimization. There are a large number of registered resources in the cloud forging service system, among which there are numerous resources meeting the task requirements of the cloud service provider, so it is necessary to optimize the cloud
forging resource service. Suppose that a cloud forging resource service request can be divided into four subtasks according to its business process, and the number of candidate cloud forging services is four, four, five and five respectively. One of each cloud service needs to be selected to complete the entire cloud forging service task. The description of tasks by the cloud service requester and the preferred attribute values of the corresponding five cloud Forging resource services are shown in Table 1.

Table 1. Task description and attribute value of optimization index.

| The service function          | Candidate cloud Forging services | Shared cost C (yuan/day) | Interaction time T (hours) | The quality of service Q | Reliability Q₁ | Credibility Q₂ | Availability Q₃ |
|------------------------------|----------------------------------|--------------------------|----------------------------|--------------------------|----------------|----------------|-----------------|
| Forging service              | A₁                               | 75                       | 19                         |                          | 2              | 2              | 2               |
|                              | A₂                               | 69                       | 15                         |                          | 2              | 3              | 3               |
|                              | A₃                               | 73                       | 17                         |                          | 5              | 2              | 5               |
|                              | A₄                               | 72                       | 18                         |                          | 4              | 5              | 3               |
| Machining service            | B₁                               | 73                       | 13                         |                          | 6              | 6              | 6               |
|                              | B₂                               | 70                       | 14                         |                          | 2              | 4              | 6               |
|                              | B₃                               | 65                       | 16                         |                          | 3              | 4              | 3               |
|                              | B₄                               | 74                       | 15                         |                          | 2              | 2              | 2               |
| Heat treatment service       | C₁                               | 74                       | 18                         |                          | 5              | 4              | 5               |
|                              | C₂                               | 71                       | 24                         |                          | 2              | 2              | 4               |
|                              | C₃                               | 73                       | 20                         |                          | 4              | 6              | 4               |
|                              | C₄                               | 77                       | 18                         |                          | 3              | 5              | 3               |
|                              | C₅                               | 69                       | 15                         |                          | 2              | 3              | 1               |
| Hardness testing service     | D₁                               | 74                       | 15                         |                          | 2              | 5              | 2               |
|                              | D₂                               | 69                       | 18                         |                          | 1              | 6              | 4               |
|                              | D₃                               | 69                       | 19                         |                          | 3              | 1              | 3               |
|                              | D₄                               | 71                       | 20                         |                          | 5              | 2              | 2               |
|                              | D₅                               | 76                       | 19                         |                          | 4              | 4              | 5               |

According to the data in Table 1, the objective function value is calculated, in which the quality weight value of each cloud forging service is set as 0.3, 0.2, 0.2, 0.3. In order to improve the efficiency of this algorithm, this study performed calculations for different combinations of Pm and Pc, and the corresponding results are shown in Figure 2.

In Figure 2, the abscissa represents the evolutionary algebra and the ordinate represents the maximum fitness. When Pc is unchanged, if Pm is taken as a small Pm, the search range will be larger, but the fitness level of convergence will be lower, and the individual varieties of its optimal population will be less. With the increase of Pm, the convergence speed also increases, which leads to the local optimal algorithm, but the global effect is not good. However, when Pm is constant, if a small Pc is used, the search range does not change significantly and the stability is not good. With the increase of Pc, the convergence speed also increases, which will lead to the local optimal algorithm, but the global effect is not good. Based on the above analysis, Pc=0.6, Pm=0.005, evolutionary algebra N = 180, and Figure 3 shows the target fitness of this algorithm.
As be seen from Figure 2 and 3, the best fitness value is 3.8387 and it can be concluded that the optimal forging cloud resource service selection results are: A2 for forging service, B3 for machining services, C5 for heat treatment service and D3 for hardness test service, namely the best cloud forging resources service portfolio as (A2, B3, C5, D3). Figure 4 shows the comparison diagram of 15 randomly selected candidate cloud forging resource service portfolios and the optimal cloud forging resource service portfolios (A2, B3, C5, D3).
It can be seen from Figure 4 that the optimal cloud forging resource service portfolio (A2, B3, C5, D3) has the lowest objective function value among the 15 portfolios. Therefore, the optimal cloud forging resource service combination (A2, B3, C5, D3) that meets the requirements and objectives of this study is finally obtained.

5. Conclusion
Under the condition that candidate resources have been determined, a cloud forging resource service optimization method based on genetic algorithm is proposed. In this paper, a cloud forging resource service optimization model is proposed, and the multi-objective decision problem is described in detail and its attribute index is quantified. By cloud forging under a wide range of network resource manufacturing environments, it can add high value-added products, reduce costs, and meet globalization of manufacturing services for production. The next steps are to develop the cloud service system and put into actual application in demonstration enterprise. Findings from the ongoing investigation will be reported separately in the near future.

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References
[1] Zissis G. Industrial Automation: A Cornerstone Shaping Industry 4.0 [President's Message][J]. IEEE Industry Applications Magazine, 2020, 26(2):4-66.
[2] Shi Fei, Xing Fan, Sun Jie, etc. Key hotspots of the "two sessions": a new stage of informatization[J]. Informatization of China. 2015,3:16-19.
[3] Yin Chao, Zhang Yun, Zhong Ting. Optimization model of cloud manufacturing services resource combination for new product development[J]. Computer integrated manufacturing systems. 2012, 18(7): 1368-1378.
[4] Cai tan, Liu Weining, Liu Bo. A new method of cloud manufacturing service optimal—selection based on intuitionistic fuzzy set[J]. China Mechanical Engineering. 2014, 25(3):352-356,421.
[5] Li Yiming. Study on complex multi-task oriented services composition in cloud manufacturing base on crossover and mutation particle swarm optimization[D]. Chongqing: Chongqing University. 2013.P22-31.
[6] Fu Chao, Xiao Ming. Optimization method of cloud service composition in cloudmanufacturing environment[J]. Application Research of Computers. 2014, 31(6): 1744-1747,1751.
[7] Han Ruifeng. The principle and application of genetic algorithm[M]. Beijing: Weapon Industry Press. 2010.