Research and Development of Cloud Manufacturing Service Composition System Based on Intelligent Optimal Algorithm

Yong-xiang LI\textsuperscript{1,2,*}, Guang-yan WANG\textsuperscript{1}, Xiao-fen HE\textsuperscript{1} and Min LIU\textsuperscript{2}

\textsuperscript{1}School of Mechanical Engineering, Guizhou University of Engineering Science, Bijie 551700, Guizhou, China

\textsuperscript{2}School of Mechanical & Automotive Engineering, South China University of Technology, Guangzhou 510640, Guangdong, China

*Corresponding author

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**Abstract.** For solving the problems of manufacturing resource allocation and industrial structure, an Intelligent Cloud Manufacturing Service Composition (ICMSC) method is proposed with cloud-entropy-genetic-algorithm. The development platform hierarchical construction and the development tools application are studied, and a CMSC system is developed. The traditional genetic operators are improved by using the normal cloud model. The improved cloud-entropy-genetic-algorithm combined with business intelligence is applied to the service composition and optimization module of CMSC system. Taking the CMSC of medical oxygen inhaler as an example, service selection, composition and optimization are carried out in CMSC system. The results show that it is feasible to apply the ICMSC method based on cloud-entropy-genetic-algorithm to CMSC system.

**Introduction**

To enhance the competitiveness of Germany's manufacturing industry, the German government has formulated the industry 4.0 strategy to promote the establishment of intelligent factories supported by the Internet of things and information physical systems [1]. In response to the difficulties such as rising manufacturing costs and weak competitive advantage of traditional manufacturing, China proposed the "Made in China 2025" plan in 2015 to realize the transformation of industrial structure to the middle-and-high level of industrial chain through the combination of physical manufacturing and virtual network [2]. Cloud manufacturing realizes the integration of entity manufacturing and virtual network. It can improve the production capacity and resource utilization of manufacturing enterprises, better solve the production and manufacturing problems of large and complex products, reduce costs, optimize resource allocation, achieve more effective collaborative manufacturing, and provide better resource services. In cloud manufacturing service composition system, resource sharing among enterprises can maximize the effective use of enterprise resources and get win-win result.

At present, the theoretical research and application of Cloud Manufacturing Service Composition (CMSC) system is in infancy. B. Li proposed a five level cloud manufacturing platform architecture [3]. O. Fatahi Valilai et al. developed a cloud manufacturing platform called STRATUS Cloud [4]. O. Morariu et al. studied the virtualization technology of enterprise manufacturing system resources in cloud manufacturing environment, and constructed a dynamic system [5]. X.V. Wang et al. developed a demand-oriented resource service cloud manufacturing system [6]. F. Tao et al designed a resource access framework based on the Internet of Things [7]. C. Duan studied the evaluation model based on AOV network [8]. L. Qu integrated the subsystems to ensure the development speed and good scalability and maintainability of cloud system [9]. D. Jiang constructed a green evaluation support system for manufacturing process based on knowledge management [10]. R. Cheng simulated
different decision-making behaviors through improved stochastic search optimization algorithm [11]. Y. Zhang et al. establishes a credit evaluation index system for SMEs under cloud manufacturing mode [12].

Some scholars have done some research on intelligent optimization algorithms. For example, J. Lartigau et al. proposed an improved artificial bee colony optimization to solve CMSC model [13]. J.R. Jovanovic et al. elaborated the scheduling algorithm of production cycle for special products in complex environment [14]. W. Gaaloul et al. proposed a dynamic mining algorithm based on statistical technology to discover composite Web services from execution logs [15]. G. Stegaru et al. proposed a quality-driven Web service composition modeling method [16]. R. Iordache et al. used genetic algorithm to calculate and compare the quality of service composition [17]. T. Berlec et al. extended optimization model of production lot sizes based on binding funds [18]. B. Florjanic et al. proposed an artificial neural network model to optimize the forming time estimation problem in die manufacturing [19]. V.R. Chifu et al. proposed an ant heuristic algorithm to solve the optimal combination of semantic Web services [20].

In summary, it can be found that a lot of research and exploration have been carried out on cloud manufacturing service composition system and intelligent optimization algorithms at home and abroad, and some research results have been achieved. However, they lack the consideration of the resources characteristics and the individual preferences of different users, and neglect the research of composition optimization algorithm. The function of service composition optimization module is weak in most cloud manufacturing systems. Based on the existing research results, this paper constructs the corresponding service quality evaluation system from the perspective of natural and social attributes, and studies the corresponding intelligent optimization algorithm.

Technical Architecture and Development of CMSC System

The integrated development environment of cloud manufacturing service composition system includes two aspects: the integrated development platform construction and the development tools selection. We use Java EE platform products to build cloud service development platform. Apache Tomcat 6.0 and MyEclipse 7.0 are chosen for the CMSC system. MyEclipse7.0 integrated development platform is an extensible integrated development platform based on Java. It can install many plug-ins. Table 1 lists several tools selected in the development process of CMSC system.

| Layers                              | Implementation technology and tools                      |
|-------------------------------------|---------------------------------------------------------|
| Terminal application layer          | Porta, JSP, JSF, Ajax                                   |
| Core function layer                 | JavaEE, MyEclipse, Tomcat, MVC, BPEL, SSH              |
| Service information layer           | Oracle, MySQL, XML                                     |
| Virtual resource layer              | Sensor, RFID, GPS, Xfire                                |
| Manufacturing Resource Layer        | Equipment, parts and components, manufacturing knowledge|
| Service Operating Layer             | Hadoop, Esper, ESB                                     |

Based on the above tools and theories, a CMSC prototype system is developed to realize service selection and CMSC optimization. The CMSC system architecture is shown in Figure 1. The contents of each layer are summarized as follows: (1) Manufacturing resource layer, which includes material resources, knowledge resources, capability resources, etc. (2) Virtual resource layer, which mainly realizes the virtualization and servitization of manufacturing resources. It provides implementation tools for on-demand cloud service supply. (3) Service information layer, which is the resource pool of the system, manages and stores all kinds of information, data and knowledge generated during the system operation, and classifies, sorts, registers, deletes and updates the resources. (4) Core function layer, which implements service search, matching, scheduling, composition, validation, evaluation
and transaction. (5) Terminal application layer, which realizes interaction between users and system, provides Web-based user interface, supports user registration, service search, service composition, service validation, etc. (6) Service operating layer, which supports capabilities such as system security, service monitoring and service bus for the system, and assists the realization of other layers’ functions. Manufacturing resource layer is the cornerstone of CMSC system, providing hematopoietic function for the system.

**Improvement of Intelligent Algorithms and Integration with CMSC System**

Considering the characteristics and objectives of CMSC, an improved genetic algorithm and business intelligence based cloud manufacturing service composition method, Intelligent Cloud Manufacturing Service Composition (ICMSC), is proposed. Its basic principle is shown in Figure 2.

The basic principles of ICMSC method are given below: (1) Customers formalize service requirements and search related services in CMSC platform through cloud manufacturing terminal application interface; (2) Customers select service composition mode and intelligent algorithm; (3) Cloud manufacturing service composition system parses the task requirements, starts the function of composition optimization and business intelligence according to customer service requirements and business processes, automatically searches, matches, combines and validates services, and recommends CMSs for customers; (4) Customers view and screen the recommended CMSs, select appropriate CMSs to compose new composite CMSs; (5) CMSC system initiates formal verification mechanism to verify customer’s choice, intelligently provides service quality information for customers, points out wrong information for composite cloud service, and puts forward revision suggestions; (6) Customer service composition operation interacts with intelligent service recommendation, formal verification and service quality evaluation until customers obtain satisfactory composite cloud services; (7) Service invocation and implementation.

The normal cloud model is used to modify the traditional genetic algorithm. Cloud Entropy Genetic Algorithms (CEGA) is designed to optimize the multi-objective optimization problem, and applied to CMSC system. The algorithm mutation and crossover operators are improved according to the cloud particles attributes of normal cloud model. In the initial stage of CEGA algorithm, the higher mutation and crossover probabilities are selected to improve the occurrence rate of the superior individuals; in the final stage, the smaller mutation and crossover probabilities are selected to keep the elite individuals in order to accelerate the global convergence rate in the population. The cross and mutation probabilities formulas of the improved cloud entropy genetic algorithm are as follows.
\[
\text{pc}= \begin{cases} 
\frac{(f-\text{Ex})^2}{2(\text{En}^n)}, & f \geq \bar{f}; \\
k_3(p_{c_{\min}} + \frac{f_{\max} - f}{f_{\max} - f_{\min}}(p_{c_{\max}} - p_{c_{\min}})), & f < \bar{f}.
\end{cases}
\]

\[
\text{pm}= \begin{cases} 
\frac{(f'-\text{Ex})^2}{2(\text{En}^n)}, & f' \geq \bar{f}; \\
k_4(p_{m_{\min}} + \frac{f'_{\max} - f'}{f'_{\max} - f'_{\min}}(p_{m_{\max}} - p_{m_{\min}})), & f' < \bar{f}.
\end{cases}
\]

where \(\text{En}=\frac{f_{\max} - \bar{f}}{C_1}\), \(\text{Ex}=\bar{f}\), \(\text{He}=\frac{\text{En}}{C_2}\), \(\text{Enn}=\text{Rand}(n)\times\text{He} + \text{En}\); \(C_1\) and \(C_2\) are control coefficients. \(p_{m_{\max}}\) is the maximum mutation probability of population; \(p_{m_{\min}}\) is the minimum mutation probability; \(p_{c_{\max}}\) is the maximum crossover probability; \(p_{c_{\min}}\) is the minimum crossover probability; \(f'\) is the fitness value of mutated individuals; \(f_{\max}\) is the maximum fitness value of population; \(f_{\min}\) is the minimum fitness; \(\bar{f}\) is the average fitness; \(f\) is the larger fitness value in the comparison of two crossed individuals. \(k_1, \ldots, k_4\) are constants of \([0, 1]\), and \(k_1=k_2=0.5\) and \(k_3=k_4=1\) are preferable.

CEGA algorithm takes service matching degree, composition harmony degree, cloud entropy, execution time and cost as five optimal objectives. Its main steps are given below:

Step 1: Initialize the population randomly.

Step 2: Compute service matching degree, composition harmony degree, cloud entropy, execution time and execution cost.

Step 3: The fitness values of each individual are calculated, and the maximum, minimum and average fitness values are calculated. The historical optimal fitness values are updated and preserved.

Step 4: Entropy \(\text{En}\), expectation \(\text{Ex}\) and hyperentropy \(\text{He}\) are calculated, and different individuals are given different crossover probability and mutation probability.

Step 5: According to the crossover probability, the double-points crossover operation is performed.

Step 6: The mutation operation is performed according to the mutation probability.

Step 7: Judge the algorithm termination condition. If the iteration number is larger than the given maximum number of iterations or the other termination conditions are reached, then the algorithm ends and the operation results are output; otherwise, the algorithm returns to step 2.

Application Example

Taking the manufacturing task of a medical oxygen inhalator as an example, the application of CMSC system is described as follows. Guangzhou Kangchengtang Medical Equipment Co., Ltd. wants to develop and produce a medical oxygen inhalator. The model is obtained by purchasing services through cloud service platform. The company plans to produce 5000 pieces of oxygen inhalator in three months. Because of its limited manufacturing capacity, it is decided to seek cloud services to help complete the production of oxygen inhalator. The main production tasks include: \(w_1\) (which includes mould design and manufacturing of flow display and control device), \(w_2\) (which includes mould design and manufacturing oxygen humidifying bottle) and \(w_3\) (which includes auxiliary parts production). Raw materials are purchased by the manufacturer in the vicinity. After processing, the finished products need to be transported back to the company.

According to the workload of human-computer interaction in the process of CMSC, the intelligent service composition method can be classified into automatic mode and manual mode. As shown in Figure 3, users can select appropriate mode and algorithm for service composition according to their needs. In the automatic mode, cloud manufacturing service composition system performs intelligent
service composition according to user-given keywords, task decomposition mode, constraints and algorithms. When service composition is performed in manual mode, cloud manufacturing service composition system searches for services according to the search keywords given by users. Users need to match and select appropriate manufacturing services manually according to their own manufacturing task requirements, and select appropriate service options for service composition. Considering the convenience of operation, the company carries out service composition in automatic mode on the CMSC platform. The company has set delivery time constraints of 2160, cost constraints of 30000 and ideal point values on the CMSC system. The automatic mode is selected in ISC service composition mode, and the cloud entropy genetic algorithm is used to optimize service composition. The system gets three cloud services. As shown in Figure 4, the corresponding values of service matching degree $V_{sum}$, composition harmony degree $H_{sum}$, cloud entropy $EnC_{sum}$, execution time $T_{sum}$ and execution cost $C_{sum}$ are 4.2, 10.872, 9.241, 1440 and 23600, respectively.

The evolutionary curve can be seen through the statistical analysis module of the system, as shown in Figure 5 and Figure 6. The distance between the optimal objective function value and the ideal point is 1.374, and the optimal fitness value of the population is 99.947.

The design and manufacture process of medical oxygen inhalator in cloud manufacturing environment is shown in Figure 7. In the product design stage, the knowledge resources such as cloud computing, transaction records and cloud manufacturing service composition system are used to carry out product demand analysis, market prediction, etc. to determine the working pressure, oxygen flow, price and cost. In the creative design stage, the knowledge resources such as engineers and cloud manufacturing service composition system can be used to determine the function, working principle, structure and material and select better creative design from the comparison of various design schemes. In the detailed design stage, with the help of UG, AutoCAD and other knowledge resources and CMSC system, the detailed design and finite element simulation analysis are carried out, and the 3D model and engineering drawings are completed. In the proofing stage, cloud manufacturing services can be searched through cloud system, and 3D printing samples, opening models and batch production can be carried out by using material resources such as CNC machine tools, knowledge.
resources such as CAD engineering drawings, logistics management and other capacity resources mapped by services. Due to the existence of cloud manufacturing environment, with the help of CMSC system, the manufacturing resources used in the design and manufacture of medical oxygen inhalator are dispersed and not entirely owned by Guangzhou Kangchengtang Medical Equipment Co., Ltd, but can be used centrally by the company, which solves the problem of new product development and manufacturing in small enterprises.

The case of medical oxygen inhaler manufacturing service composition shows that it is feasible to apply the intelligent service composition method based on cloud-entropy-genetic-algorithm to CMSC system. Its multi-objective optimization and different service composition modes can meet users’ needs of different-levels manufacturing tasks.

**Conclusion**

An Intelligent CMSC method is proposed with cloud-entropy-genetic-algorithm is proposed and applied to CMSC system. A CMSC system is developed. The improved cloud-entropy-genetic-algorithm combined with business intelligence is applied to the service composition and optimization module of CMSC system. Taking the CMSC of medical oxygen inhaler as an example, service selection, composition and optimization are carried out in CMSC system. The results show that it is feasible to apply the ICMSC method based on cloud-entropy-genetic-algorithm to CMSC system.

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