IEEE Access
Multidisciplinary | Rapid Review | Open Access Journal

Received November 29, 2019, accepted December 22, 2019, date of publication December 25, 2019, date of current version January 27, 2020.

Digital Object Identifier 10.1109/ACCESS.2019.2962248

Modeling of Cloud 3D Printing Service Hyper-Network in Service-Oriented Manufacturing Systems

CHENGLEI ZHANG[1,2], FEIYU ZHAO[3], AND ZHENQIAN WANG[1,2]

[1]School of Mechanical and Vehicle Engineering, Linyi University, Linyi 276000, China
[2]Institute of Industrial Design and Intelligent Manufacturing, Linyi University, Linyi 276000, China
[3]School of Mechanical and Electrical Engineering, Wuhan University of Technology, Wuhan 437000, China

Corresponding author: Chenglei Zhang (zhangchenglei@lyu.edu.cn)

This work was supported in part by the Natural Science Foundation of Shandong Province of China under Grant ZR2019PEE019, in part by the High-Level Talents (high-level doctorate) Research Project of Linyi University under Grant LYDX2019BS009, and in part by the National Key Technology Research and Development Program under Grant 2016YFB1101700.

ABSTRACT According to the theory of a complex network, the overall characteristics are derived from complex interactions among its components, that is, network structure. For its service network, its overall characteristics are its functions. In view of the coordinated linkage between the 3D printing industry and the logistics industry, 3D printing is deeply integrated with Internet technology, digital casting technology and Internet + service platforms. We propose a hyper-network model of raw material suppliers, semi-finished product processors and finished product manufacturers that realize on-demand customization. To analyse, design, and build the cloud 3D printing manufacturing capability service competition network, we propose a 3D printing service node structure model based on a super network using a reference and cloud manufacturing service model. The model's mathematical structure is given in detail. Under this condition, it is necessary to discuss the interaction between the logistics service level, productivity level and product processing quantity. The process of the proposed model and method is given, and the validity is proven with a case study of a Cloud 3D printing service hyper-network in service-oriented manufacturing systems.

INDEX TERMS Complex network, manufacturing resource services, service-oriented manufacturing (SOM), cloud manufacturing, cloud 3D printing, order-driven.

I. INTRODUCTION

In the socialization process of advanced manufacturing systems (AMSs), the applications of the Internet of Things (IoT), big data and cloud technologies in manufacturing play increasingly important roles [1]. According to these concepts and techniques, the proposed service-oriented manufacturing (SOM) systems (e.g., cloud manufacturing (CMfg) and cloud-based design and manufacturing) are attracting increasing attention from researchers [2]. The existing related works primarily focus on the following aspects.

Considering manufacturing capability services, there are essential differences between cloud 3D printing services (C3DPSs) and traditional resource services that are related to the participation of people [3]. Especially when the dynamic events and uncertainty of the CMfg environment are considered [4], how to allocate optimal services for random arriving tasks is a issue worthy of study. The dynamic task scheduling problems in different manufacturing systems have been studied for years [5]. Typical methods for it include agent-based approach [6], [7], heuristic-based approach [8], real-time process information method [9], workflow-based method [10] and pheromone based approach (Renna 2010). The manufacturing capability service of C3DPS has more similar human behaviour characteristics [11]. There are various logical relationships among their manufacturing capability services. Therefore, these relationships are not unique but rather the coexistence of various relationships [12]. Social networks mainly refer to networks that are composed of complex connections between social individuals and individuals. According to the related theory of a social network, the manufacturing capability service in a C3DPS service platform is built into an online social network that relies on these complex relationships [13], [15].

The associate editor coordinating the review of this manuscript and approving it for publication was Shagufta Henna.

This work is licensed under a Creative Commons Attribution 4.0 License. For more information, see http://creativecommons.org/licenses/by/4.0/

C3DPSs involve many industries, knowledge and data scales, and there are problems of understanding ambiguity and non-standard terminology in the natural language description [14]. At present, the format of the exchange between those services' and the order tasks' information with cloud 3D printing (C3DP) is not uniform, which affects the efficient processing of order task and service matching in the C3DPS platform [16]. To solve the ambiguity between those services' and order tasks' information, complex and heterogeneous resources are required along with unified description and modelling [17]. The process of executing the C3DP order task (C3DPOT) can be regarded as a series of C3DP services that are combined according to a certain timing and logical relationship to complete the corresponding manufacturing task activity. It is an organic collection of those services' and tasks' active objects (such as order type, processing process, delivery time, and product material) on time, information, and physical flow [18]. The modelling and digital description of C3DP tasks and services are the basis for information monitoring and processing in the execution process of C3DP tasks based on order-driven tasks [19]. This order tasks model and services model can formally represent its information and effectively integrate and manage the data of those service and manufacturing tasks. Additionally, the information description in each stage of the C3DPOT execution process is not only a formal semantic description of the equipment resources but also a potential source of sensitive information such as semantic description, knowledge discovery, matching and combination. How to use the online store, reasoning, query, and access to knowledge and information by these formally defined task knowledge and data with the C3DPS order is the basis for constructing the C3DPS platform.

The purpose of establishing a cloud 3D printing service-oriented model is a descriptive model of C3DPSs, which easily directly matches the demand of the manufacturing task on the demand side, thereby realizing the transaction of services. However, the probability of these services being single-invoking is small, especially for the personalized design requirements of innovative and creative products in the whole product life cycle. Based on this idea, the best group of services is usually selected and combined with several services [20]. Considering that the manufacturing service description model in the traditional cloud manufacturing service portfolio can only be matched with the manufacturing task requirements, a C3DPS network is proposed, which can realize a self-organizing cluster among C3DPS resources [21].

Therefore, considering the aforementioned characteristics, to ensure the quality and efficiency of manufacturing services in cloud environments [22]. The main contribution of this work is that a complex network-based method is proposed to respond to the dynamic arrival of tasks in order to select the current optimal services for sub-tasks according to the real-time status of the candidate services and shorten the task execution time [23]–[25]. By abstracting manufacturing services to the nodes of networks and regarding the various

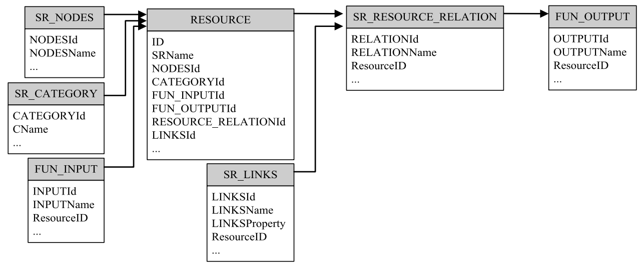


FIGURE 1. The logical relationship diagram between the main node.

correlations among those heterogeneous nodes as the edges of networks, the manufacturing service network is modeling to address complex manufacturing service management in the cloud environment.

II. THE SELECTION OF C3DPS NODES AND DESIGN OF THE DATABASE

Using these C3DPSs in the associated network as the object of research, the structure of the manufacturing capability information model is described and processed such that they are realized in a specific way, including the extraction and classification of various feature attributes in the model. On this basis, this paper proposes a method in which the different characteristics of forms and granularity information are described by DDL and formed by the relationships between manufacturing capability services[26]. Therefore, these dynamic services realize on-demand delivery by manufacturing capability.

A. THE CONSTRUCTION OF THE C3DPSs NODE TABLE

To meet the modelling requirements of various service resources in the virtual resource pool, it is necessary to create many different types of unstructured or arbitrary format fields, convert them into corresponding structured data, and establish a corresponding database and data warehouse according to the specified structure. As shown in Fig. 1, it is a logical relationship diagram between the main node.

where this corresponding database and data warehouse include the following data tables, such as the manufacturing resource table, service resource node table, service resource classification table, service resource function input table, service resource function output table service resource relationship table, and service constraint table.

Considering the alternative relationship between manufacturing services, that is, when two atomic tasks are executed in a serial sub-sequence, their logical relations are equal, and the two atomic tasks are joined into an edge [27]. When the weight of the manufacturing capability is adjusted, the granular tasks are divided into different coarse and fine-grained manufacturing capabilities, and the alternative relationship of manufacturing capabilities is formed into an atomic task relationship network among business-level manufacturing service sets. Here, the Multi-Dimension-ality of directionless edges in the C3DPSs set is not considered [28].

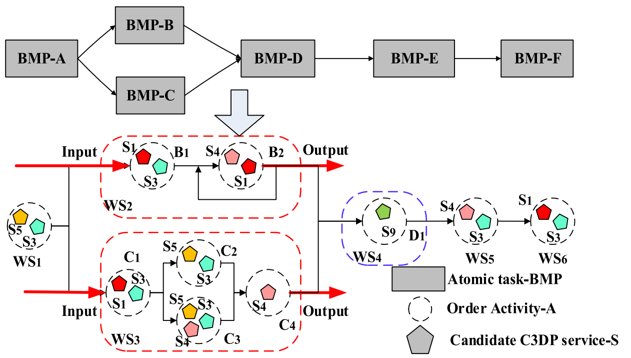


FIGURE 2. The diagram of the relationships between C3DPSs and C3DPSs.

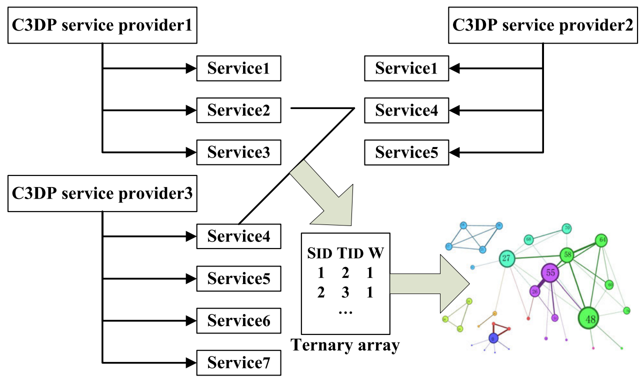


FIGURE 3. The diagram of the manufacturing capability service association network.

Taking the user's demand as an example, portrait 3D printing is divided into six sub-tasks: portrait scanning, cartoon image design and modelling, model slicing, portrait 3D printing, surface post-processing, and coloring [29]. Each sub-task corresponds to its own business process, namely, BMP-A, BMP-B, BMP-C, BMP-D, BMP-E and BMP-F. As shown in Fig. 2, it is a diagram of the relationships between C3DPSs.

where BMP-B is composed of both the data model and multiple business logic activities in accordance with cartoon image design and cartoon image modelling. The logical relationship between two business logic activities is serial order and loop, and the constraint condition is that the two steps have a sequence relationship. For example, this model slice process is composed of the data model, and two business logic activities form the sub-task, and the relationship between the two business logic activities in this step is sequential and parallel.

B. THE FORMAL DESCRIPTION AND ASSOCIATION DEFINITION OF THE C3DPS

Association relation refers to the structural relationship between two or more types of objects [30]. The combinable association relation is a special case of the association relationship; that is, this C3DPS is also an association relation in which the combinable association relation exists in the functional feature description and the functional connection structure. In view of this, the judge-ment of C3DPSs composable association relation mainly represents whether there is a combination of input and output function relationships between two C3DPSs.

Definition (Relationship of Services, RoS) 1: The relationship of C3DPSs:

$$RoS = \{R_1, R_2, R_3, R_4, R_5, R_6\} \tag{1}$$

where R_1 represents its replacement relationship, R_2 is a complementary relationship, R_3 is a joint relationship of service combinations, R_4 is a support relationship of single input and output, R_5 is a support relationship of multiple input and single output, and R_6 is a support relationship of single input and multiple outputs.

The input/output of any two services $C3DPS_i$ and $C3DPS_j$ in the cloud 3D printing virtual resource pool is expressed as:

$$C3DPS_i: Input_i = \{Input_{i1}, Input_{i2}, \ldots, Input_{im}\}$$
$$Output_i = \{Output_{i1}, Output_{i2}, \ldots, Output_{in}\} \tag{2}$$
$$C3DPS_j: Input_j = \{Input_{j1}, Input_{j2}, \ldots, Input_{jm}\}$$
$$Output_j = \{Output_{j1}, Output_{j2}, \ldots, Output_{jn}\} \tag{3}$$

where $l(i, j)$ represents an association relation of any two services $C3DPS_i$ and $C3DPS_j$.

If the relationship between two services $C3DPS_i$ and $C3DPS_j$ is not equal, this weight coefficient will also be strained one by one. The specific situation is as follows:

(1) If $l(i, j) = R_1$, then $\omega_{ij} = T = n$.
(2) If $l(i, j) = R_2$, then $\omega_{ij} = T < n$.
(3) If $l(i, j) = R_3$, then $\omega_{ij} = m = n$.
(4) If $l(i, j) = R_4$, then $\omega_{ij} = T = m$.
(5) If $l(i, j) = R_5$, then $\omega_{ij} = m < T$.
(6) If $l(i, j) = R_6$, then $\omega_{ij} = T < m$.

where $l(i, j) = R_3$ represents a joint relationship of services, and $l(i, j) = R_1$, $l(i, j) = R_2$, $l(i, j) = R_4$, $l(i, j) = R_5$, and $l(i, j) = R_6$ are all in a state in which they can be combined.

The C3DPS association network is a complex network that covers all granularities and the relationship between services. Its core is the service node and service relationship (edge). The expression of the mathematical set is as follows:

$$G = \{V, E, W\} \tag{4}$$

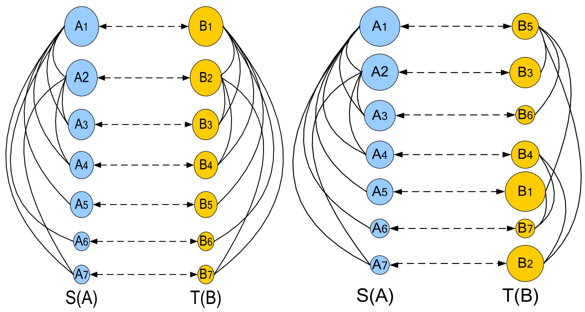
where $V = \{C3DPS_1, C3DPS_2, \ldots, C3DPS_n\}$ is a set of all C3DPSs in the virtual resource pool, $E = \{< C3DPS_1, C3DPS_j > | C3DPS_{ij} \in V, 1 \le i, j \le n\}$ is a set of services that have an association relationship between these C3DPSs, and $W = \{\omega_{ij} | 1 \le i, j \le n\}$ is a weight set in which an association relationship exists.

C. THE CONSTRUCTION OF THE C3DPSs MODEL

Taking C3DPSs as an example, the specific process of the cloud 3D printing manufacturing capability service model is shown in Fig. 3.

TABLE 1. The table of the basic information of C3DPS nodes.

```
--Create table
Create table C3DPS_NODES{
ID NUMBER not null,
ORDERNAME VARCHAR2(100), //Order name
ORDERCATEGORY VARCHAR2(50), //Order classification
SERVICECATEGORY VARCHAR2(50), //Service type
PRINTMATERIAL NUMBER, //Printing material
PROCESSINGTECHNOLOGY VARCHAR2(50), //Processing technology
STATUS VARCHAR2(1), //Access status
REMARK VARCHAR2(200)}
```



(a) Similar coupling (b) Random coupling

FIGURE 4. The diagram of the coupling relationship between C3DPSs nodes.

First, the nodes are selected; that is, all these C3DPS resources in the virtual resource pool are selected. There are a considerable number of C3DPS resources of different sizes. Therefore, this paper takes these service providers as the object from a macroscopic perspective and establishes the basic information table of C3DPS nodes, as shown in Table 1. The specific expression is as follows:

Second, the decoupling problem and dimension-reduction in C3DPSs is addressed; that is, they change in the isolation and reduced complexity between C3DPSs and manufacturing tasks. When these service features are de-redundant, it leads to slow recognition speed and weak classifier performance of high-dimensional data in this complex network [31].

Here, the premise of the decoupling problem is first identified in the coupling. The coupling refers to the phenomenon that two or more systems or two forms of motion (such as agglomeration between services or tasks) can interact with each other. In the C3DPS network, there are two coupling methods: similar coupling and random coupling. Similar coupling means that nodes in any two groups of networks are clustered according to the degree of connectivity, and the dependencies of nodes are constructed [32]. As shown in Fig. 4 (a), the connectivity values of S3 and S6 are equal or very similar, and this phenomenon of between nodes has the feature of similar coupling. The random coupling refers to the phenomenon of random coupling relationships between nodes in any two groups of networks, as shown in Fig. 4 (b).

A common decoupling method ignores or simplifies a motion that has less impact on this coupling problem under study and only analyses the main motion (such as changes in

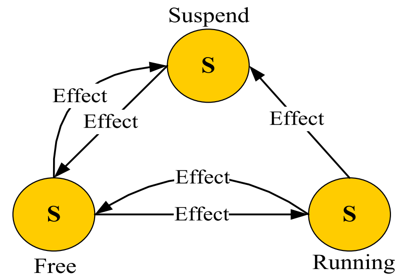


FIGURE 5. The diagram of C3DPSs status.

the state of the C3DPSs). Therefore, the essence of C3DPSs decoupling is weakened by the coupling strength of the dependent network in a complex network environment. In the C3DPSs, these nodes can be changed into an independent node in the *S_Network*, so that it does not have functional dependency. This process of transforming dependence is called the decoupling process of C3DPSs.

Taking the design and processing of innovative creative product parts as an example, the decoupling process of the C3DPSs is described as follows:

For the design and processing of innovative creative product parts, the state set can be set, such as free, running, and suspend, as shown in Fig. 5.

where StateSet={S(Free),S(Running),S(Suspend)}. The set of state transitions is expressed as:

$$\begin{aligned} StateSet(S1) = \{&S\,(Free) \Leftrightarrow S\,(Running)\,, \\ &S\,(Running) \Leftrightarrow S\,(Suspend)\,, \\ &S\,(Free) \Leftrightarrow S\,(Suspend)\} \end{aligned} \tag{5}$$

Taking the Running state as an example, it is expressed as:

$$Trans_{S(free)\Leftrightarrow S(running)} = (Ps, Es) \tag{6}$$

where Ps is a precondition for performing state transition, such as the state of S1 is idle, and Es is an effect of performing state transition, such as the state of S1 is running;

Here, the innovative creative product parts services can provide the following functions:

$$C3DS = (Fun1, Fun2, \cdots, Fun7) \tag{7}$$

In addition, each function has a certain execution process. For example, the processing of the portrait 3D model is Fun1, which is the process of part shape design – model slice – 3D printing – test delivery, as shown in Fig. 6 and can be expressed as follows:

$$\begin{aligned} Process(Fun1) = \{&P_1 \rightarrow P_2, P_1 \hookleftarrow P_2, \\ &P_2 \rightarrow P_3, P_3 \rightarrow P_4, P_3 \hookleftarrow P_4\} \end{aligned} \tag{8}$$

where $P_1 \rightarrow P$ represents that P_1 and P_2 are sequential relations, and $P_1 \hookleftarrow P_2$ represents that P_1 is dynamic feedback in accordance with the execution result of P_2.

According to the dependency strength of C3DPSs nodes, the threshold λ of dependency intensity (determined by experts according to the actual situation) is set, and the C3DPS nodes are merged or decomposed without other influence, as shown in Table 2.

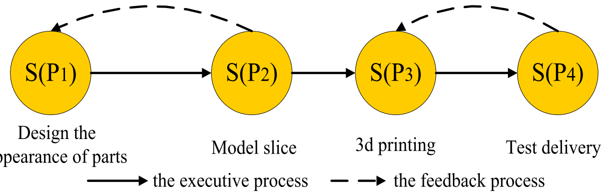
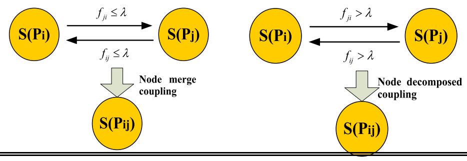


FIGURE 6. The diagram of the C3DPSs execution process.

TABLE 2. The coupling merged or decomposed operation table of C3DPSs nodes.

OPERATION	NODE MERGED COUPLING	NODE DECOMPOSED COUPLING
Conditions	$f_{ij} \geq \lambda$ AND $f_{ji} \geq \lambda$	$f_{ij} < \lambda$ OR $f_{ji} < \lambda$
Instance		

1) THE NODE MERGE DECOUPLING

If $f_{ij} \geq \lambda$ and $f_{ji} \geq \lambda$ exist, the two nodes with coupling relationships are merged into one new node $S(P_{ij})$.

2) THE NODE DECOMPOSED COUPLING

If $f_{ij} < \lambda$ or $f_{ji} < \lambda$ exists, the node decomposed coupling operation is performed; that is, the smaller f_{ij} is deleted and assigned a new empirical value e.

Third, the relationship between service nodes is determined.

According to the input and output information of services, these characteristics and relationships are described by a series of attributes of nodes or edges in this C3DPS network, and the weights and the triple data structure table of the association relationships between the services are determined.

For these C3DPSs, the input and output are mainly in the form of services. Considering the alternative relationship between C3DPSs, the service providers take the candidate service set with equal or different similarity matching as the output alternative service.

Taking portrait 3D printing as an example, the C3DPSs network is represented by the form of an adjoining matrix in traditional graph theory. In this process, these nodes are selection, decoupling and multidimensional reduction, and then the matrix is constructed into a corresponding adjacency matrix. The part transaction data are selected, and a corresponding adjacency matrix is generated as follows:

$$A = \begin{bmatrix} 0 & 3 & 0 & 1 & 1 \\ 3 & 0 & 1 & 2 & 0 \\ 4 & 2 & 0 & 0 & 0 \\ 0 & 2 & 0 & 0 & 1 \\ 1 & 0 & 0 & 1 & 0 \end{bmatrix}$$

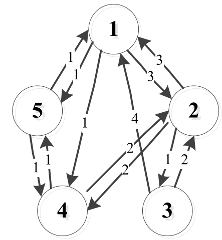


FIGURE 7. The diagram of the part network.

Source node	Target node	Weight
1	2	1
1	4	1
1	5	1
2	1	1
2	3	1
2	4	1
3	1	1
3	2	1
4	2	1
4	5	1
5	1	1
5	4	1

FIGURE 8. The triples of transaction data.

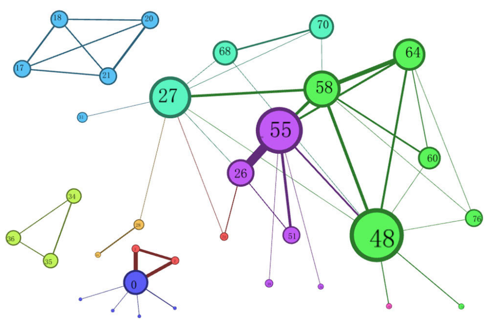


FIGURE 9. The digraph of the portrait 3D service node in the *S_Net*.

Thus, the complex network is a directed logical network that this corresponding adjacency matrix is not easy to deal with the types and parameters. Therefore, the network represents the form of triples in which the adjacent edges can be calculated. As shown in Fig. 8, the triplet form of portrait 3D printing is shown in Fig. 7.

Finally, the nodes and edges of all C3DPSs are determined.

According to the historical C3DPSs data, the nodes and edges form a complex network topology, as shown in Fig. 9, that is imported to Gephi 0.8.1.

III. THE PROCESS OF MULTI-DIMENSIONALITY REDUCTION IN C3DPSs

Because of the high-dimensional data in the network characteristic, the redundant features and the large scale of data records and attributes result in slow recognition speed and weak classifier performance [33]. Thus, the process of

Multi-Dimensionality reduction in the C3DPS network maps to its C3DSs. The process of Multi-Dimensionality reduction in C3DPSs is as follows:

A. FEATURE RECOGNITION

Taking the construction of the C3DPS network as an example, it is used to cluster by the computer program. The basic data of the network must be described as a graph in the form of database tables; the database table is the structure of the 3D printing service network [34]. Because the task-service network is a directed logical network, the adjacency matrix is convenient for computer processing, and it is not convenient for the expression of the logical network. Therefore, this service network topology is expressed in a triple in which the construction process of the network is divided into the following steps:

1) THE INITIAL STATE OF THE C3DPS

According to the QoS indicators, MS_{QoS} is set between 0 and 1, representing time, service cost, service quality, credibility, reliability, etc. Here, each node is configured to a service load factor threshold i for setting the number of connections.

If the point set of the C3DP service satisfies the condition of $S = (S_1, S_2, \ldots, S_N)$, j is the total number of service points, and $S_i = (x_i, y_i)$ represents the coordinates of the i-point. Taking the node of the complex network as each point set of $S = (S_1, S_2, \ldots, S_N)$, the distance of the relative positions is calculated as the connected side between each pair of S_i and S_j. The formula is expressed as:

$$d(S_i, S_j) = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \tag{9}$$

$Poly(G)$ can be represented by a weight value matrix $A(G)$ of n-order. The weights of S_i and S_j are expressed as:

$$w_{ij} = d(S_i, S_j) \tag{10}$$

Thus, a fully connected network is constructed. It is a normalizing calculation.

This constructs a fully connected weight network, normalized processing calculation:

Thus, a fully connected network is constructed and normalized weighting processing and a formula to calculate the weights:

$$W = \frac{W'}{\max(w_{ij} \in W')} \tag{11}$$

If a threshold is $t \in [0, 1]$, C3DPS is divided by operator $D_t(W)$. When the connection weight of a pair of nodes is greater than or equal to t, there is no connected edge between the two nodes in the $S\_Network$. Otherwise, there is a connection edge between the two nodes.

The expression of the operator $D_t(W)$ is:

$$A_t = D_t(W) = \begin{cases} 0, & w_{ij} \geq t \\ 1, & \text{other} \end{cases} \tag{12}$$

where A_t is the adjacency matrix of a complex network when the threshold is t, $a_{ij} = 0$ indicates that there is no connection between S_i and S_j, and $a_{ij} = 1$ represents a connection between S_i and S_j.

2) THE INCREASE IN COMPUTING NODES

The process of web service optimization based on QoS: in a certain period of time, any new service resource node has a cooperative relationship with several nodes, and there exists a phenomenon that is a high preference and high value of QoS attribute [35]. Its selection probability is as follows:

$$\prod_i = \frac{MS^i_{QoS}}{\sum_{i=1}^{n} MS^i_{QoS}} \tag{13}$$

3) THE REDUCTION IN COMPUTING NODES

To solve the problem of computing resource allocation, it is proposed that the requested service network manages and schedules a large number of computer resources in a unified way so that these computer resources can be properly allocated or compensated for the shortage of computing resources and deleted in the lower quality of service [36]. Here, any node is calculated by the randomly selected nodes that select an associated relationship. Its selection probability is as follows:

$$\prod_i' = \prod_i = \frac{\frac{1}{MS^i_{QoS}}}{\frac{1}{\sum_{i=1}^{n} MS^i_{QoS}}} = \frac{\sum_{i=1}^{n} MS^i_{QoS}}{MS^i_{QoS}} \tag{14}$$

4) THE INCREASE IN EDGES

At a certain point in time, the collaborated nodes will be affected by the association relation of new nodes, and then it changes the weight value or the number of nodes and edges. If a new node is added, the weight value of the new edge is 1; otherwise, the weight of the edge increases by 1.

5) THE REDUCTION IN EDGES

If these nodes or edges of the collaborated nodes are deleted, then the weight value is reduced by 1.

6) THE CONSTRAINTS OF THE CONNECTED SERVICE NODE

For a certain period of time, C3DPSs can be used without restrictions, but the node connection is limited by the degree of service capability. After associating with another manufacturing service, the node load factor MS^j_{load} will increase. If $MS^j_{load} \geq 1$, the manufacturing service node *Kronecker* cannot be associated with other nodes.

7) THE ADAPTIVE EVOLUTION OF MANUFACTURING SERVICES

Every two times, MS_{QoS} is adjusted and corrected to ensure that excellent service can be provided with a higher QoS index value.

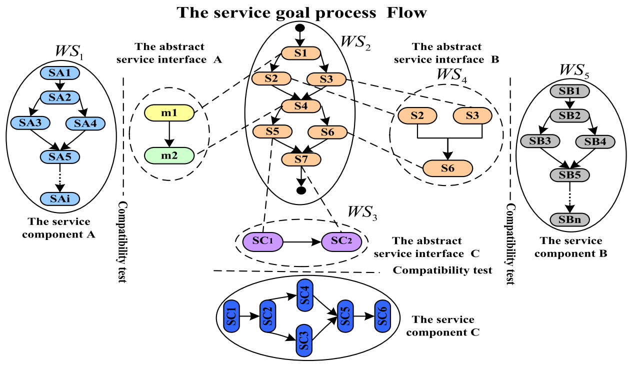


FIGURE 10. The schematic diagram of the relationships between C3DP services.

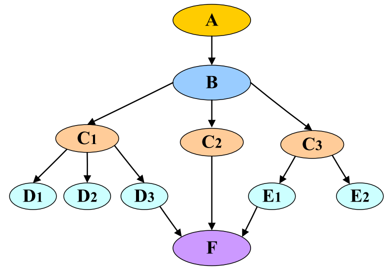


FIGURE 11. The tree structure diagram of the C3DP resource template node and root template node.

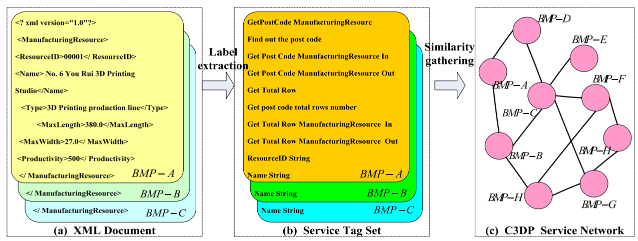


FIGURE 12. The diagram of tag extraction and similarity matching based on XML documents.

B. THE MULTI-DIMENSIONALITY REDUCTION IN THE SERVICE NODE

Due to a certain correlation between information features, the Multi-Dimensionality reduction in service node features can effectively reduce the redundancy in information, which is conducive to the selection and description of service nodes [37]. Here, the original data are calculated by principal component analysis and reduced to one-dimensional data:

$$F = [k_\lambda(T_0), k_\lambda(T_1), \ldots, k_\lambda(T_N), k_{\max}(T_0), k_{\max}(T_1), \ldots, k_{\max}(T_N)] \quad (15)$$

where $k_\lambda(T_i)$ represents a threshold of the average degree of the complex networks at T_i; $k_{\max}(T_i)$ is a threshold of the maximum degree of the complex network at T_i.

The difference between the degree thresholds on the comprehensive indicators:

$$\Delta F = [\Delta k_\lambda(T_0), \Delta k_\lambda(T_1), \ldots, \Delta k_\lambda(T_N), \Delta k_{\max}(T_0), \Delta k_{\max}(T_1), \ldots, \Delta k_{\max}(T_N)] \quad (16)$$

where $\Delta k_\lambda(T_i) = k_\lambda(T_i) - k_\lambda(T_{i-1})$ represents the difference between the average degree thresholds of the complex network at T_i, and $\Delta k_{\max}(T_i) = k_{\max}(T_i) - k_{\max}(T_{i-1})$ represents the difference between the maximum degree thresholds of the complex network at T_i.

IV. CASE STUDY

Taking portrait 3D printing as an example, the user-submitted manufacturing task is divided into six sub-tasks by the service demand decomposition module: portrait scanning, cartoon image design and modelling, model slicer, 3D printing, surface post-processing and colouring. Each sub-task (such as BMP-A, BMP-B, BMP-C, BMP-D, BMP-E, and BMP-F) corresponds to any one of a set of candidate C3DPSs, WS_1, WS_2, WS_3, WS_4, WS_5 and WS_6. As shown in Fig. 10, a schematic diagram of the relationships between C3DPSs and C3DPSs is shown.

where BMP-B is composed of different business logic modules according to cartoon image design and cartoon image modelling activities. The BMP-B logical relationship between two business logistics is concatenation and loop, and the constraint condition is that the two steps have a sequential relation [38]; BMP-C is composed of multiple sub-tasks, and the constraint condition is sequential and parallel.

A. THE SERVICE TEMPLATES FOR C3DP SERVICES

The C3DPS template is built according to the guidance of information resources, human resources, and technical guidance, so its sub-template can be derivation, overload and inheritance on its father-templates. Therefore, the derived resource template node and root template node can be generated to a tree structure diagram, as shown in Fig. 11.

where node A is a virtual resource template tree root node of the C3DP resource, which is the base class of the resource template and derived from all C3DP resource templates, B is a single resource template directly derived from the A class, C1, C2 and C3 are the sub-nodes in the C3DP resource template tree, which are derived from B class, D1, D2 and D3 are child nodes derived from C1 class, E1 and E2 are derived from class C3, and F class is a sub-class of C2, D3 and E1, which are multiple inheritance relationships.

As a container of information, the service templates mainly describe the corresponding content of the C3DP service and its attributes and manufacturing capabilities. XML is a file format that is described in text form and has the function of tagging resource attribute information. It is used to tag the data for C3DP services based on the definition of XML data. Based on this, this paper parses the grammatical features of service templates and extracts API function interactive aggregation by C3DP services. Finally, the service network is constructed as an order task execution behavior constraint of the order task, as shown in Fig. 12.

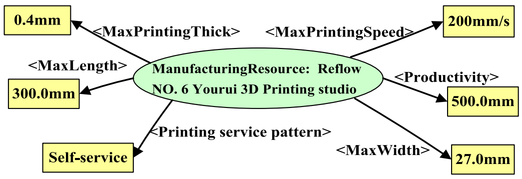


FIGURE 13. The node relationship of C3DP services.

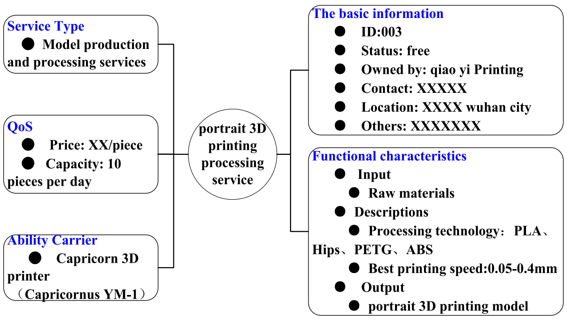


FIGURE 14. The description diagram of C3DP service.


```
<? xml version="1.0"?>
<ManufacturingResource>
  <ResourceID>00001</ ResourceID>
    <Name>NO. 6 Yourui 3D Printing studio</Name>
    <Type>3D printing production line</Type>
    <MaxLength>380.0</MaxLength>
 <MaxWidth>27.0</ MaxWidth>
<Productivity>500</ Productivity>
      ...
</ ManufacturingResource>
```


FIGURE 15. Part XML graph information of the C3DP service template.

TABLE 3. The basic information of the service node.

```
--Create table
create table C3DS_NODES {
ID INTEGER not null,
NAME VARCHAR(100), //Order Name
ORDERCATEGORY VARCHAR(50), //Order Category
SERVITYPE VARCHAR(50), //Service Type
PRINTMATERIAL NUMBER, //Printing Materials
PROCESSINGTECHNOLOGY VARCHAR(50),
//Processing Technology
STATUS VARCHAR(1), //Access Status
REMARK VARCHAR(200)}
```

B. THE MODELLING PROCESS OF THE C3DP SERVICE NETWORK

Taking the construction of the C3DPS network as an example, it is used to cluster by the computer program. The basic data of the network must be described as a graph in the form of database tables; then, the database table is the structure of the 3D printing service network. Because the task-service network is a directed logical network, the adjacency matrix is convenient for computer processing, and it is not convenient for the expression of the logical network. Therefore, this service network topology is expressed in a triple in which the construction process of the network is divided into the following steps.

First, we express the information of the C3DP service. According to the characteristics of many types and different capabilities, the C3DP service template is expressed in the XML format to assemble resources for personalized design products. For example, some attributes of NO. 6 You-rui 3D Printing studio include 3D Printing Service Mode, 3D Printing Specification Size, Printing Accuracy, Printing Maximum Speed, 3D Printing Device Model, and Printing Type. There is a node relationship, as shown in Fig. 13. As shown in Figs. 14 and 15, a C3DP service is represented as in the XML format. Additionally, the C3DP service also expresses the logical relationship among the resource-attribute-attribute values.

Second, we identified the service nodes. Here, ten C3DP service providers are selected as the research object and established by the basic information table of nodes, as shown in table 3. The specific process is described in the PL/SQL programming language as follows:

Here, the C3DP service network is clustered by the program programmed in the software. Therefore, the triple data of personalized cultural creative design products is described as a graph in the form of database tables, and it is generated in the complex network topology structure. Among them, the basic information of the portrait 3D printing node and the data attribute of the C3DP service node are shown in Table 4.

Third, determine the substitutable relationship between C3DP service providers (that is, the service providers can provide a competitive relationship with the same or similar services). On this basis, the substitutable relationship is created in the table of connective relationships.

Due to the different network integrated service capabilities of each C3DP service provider, it is necessary to separately research the candidate services that are connected to each service node [39]. There are many abilities of the service provider on the same output, such as Jiayi Hi-Tech service provider providing 3D scanner outsourcing services, and Yourui service provider providing 3D scanner outsourcing services. Then, a similar weight is 1. After all the data of the C3DP service are summarized, the node connective relationship is generated in the form of a database table, as shown in table 5.

Finally, the basic information table and connective relationship table data of the C3DP service node are imported and analyzed in Gephi-0.8.1 software. At present, the research of MFG services modelling focuses on the service description of resource discovery matching. The purpose of the research is to establish a service-oriented description model, which can easily directly match the MFG task requirements and the demand-side MFG side, and then realize the result delivery.

C. RESULTS AND COMPARISON

To illustrate the availability and efficiency of the proposed Cloud 3D printing service hyper-network method in service-oriented manufacturing systems, hyper-network

TABLE 4. The data attribute of the C3DP service node.

Row-Key	Time-Stamp	Columns			
		ORNAME	ORCATEGORY	PRTECHNOLOGY	PRMATERIAL
00001	0	Bas Brahma décor plaster moulding	1	Plaster 3D printing (PP)	Plaster materials
00002	0	R2D2 robot	3	Selective laser sintering (SLS)	Mineral powder
00003	1	Hole cube model	1	Stereo lithography apparatus (SLA)	Photopolymer
00004	0	Eiffel Tower	7	Fused deposition modelling (FDM)	Thermoplastic materials

TABLE 5. The table of connective relationships.

```
--Create table
create table C3DS_NODES
{
ID NUMBER not null,
SOURCE NUMBER, // The source node
TARGET NUMBER, // The target node
TYPE VARCHAR2(20), // Node type
WEIGHT NUMBER   //Node weight
}
```

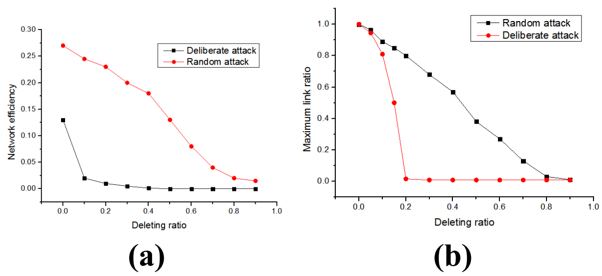


FIGURE 16. A diagram of the relationships between the maximum link ratio and the ratio of deleted nodes.

method is compared with other traditional method, including Exact matching, Contains matching, Implicit matching and Mis-matching.

On the basis of a detailed analysis of each matching index, the matching index's data sets are simulated with the traditional MFG service modelling method and 4 types of similarity algorithms based on a complex network. All the algorithms' codes are written on the MATLAB experimental platform. In the Windows 7 operating system, the CPU is an Intel i3-2120 (3.30 GHz) and 4G memory [40]. In the experiments, 90% of five data sets were selected as training sets, 10% as test sets, and the number of independent experiments was 1,000. The resulting accuracy(AUC) values of the traditional MFG service modelling method and 4 kinds of similarity algorithms based on complex networks are shown in Table 6:

The diagram of relationships between the maximum link ratio and the ratio of deleted nodes is shown in Fig. 16 (a) and (b).

TABLE 6. The resulting auc values (%) of the traditional method and 4 kinds of similarity algorithm based on a complex network.

Indexes	Types	The traditional method				4 kinds of similarity algorithm based on complex network			
		Exact matching	Contains matching	Implicit matching	Mis-matching	NS	Grid	Yeast	PB
	HPI	3.561	2.654	1.201	0.051	0.967	9.534	2.425	0.870
	CN	2.995	1.325	1.235	0.062	0.267	2.481	0.701	0.375
	PA	3.056	1.254	1.204	0.031	0.735	7.992	1.684	0.523
	AA	1.854	1.025	1.054	0.048	0.450	5.161	1.186	0.469
	RA	2.056	2.985	1.069	0.028	0.365	3.114	0.891	0.443
	CI	1.952	1.985	1.211	0.034	0.384	3.150	0.931	0.590

By comparing and analyzing the experimental results in Table 5, the data set experimental results show that the combined index CI algorithm is more accurate than the traditional method and the existing 4 algorithms in five different domain networks, which further improves the accuracy of link prediction and has better prediction results for complex networks; that is, the universal applicability is better. Meanwhile, the visualization of the NS network is shown in Fig. 16. Except for the PA indicator, the other five indicators have the highest AUC value, which may be related to the large module degree caused by the comparison of the traditional method and 4 kinds of similarity algorithms based on complex networks. Considering the theoretical time complexity of the algorithms, the common neighbour algorithm first finds the pair of nodes and then calculates the number of common neighbours. Therefore, the time complexity of the algorithm is 220(k N). On this basis, the AA and RA indicators are calculated to neighbours.

Therefore, the proposed C3DPS network modelling method maintains the same time complexity as the traditional modelling method, and the accuracy is improved. Here, the running time of the algorithm is also tested. As shown in Table 7, the actual elapsed time of CI is relatively short, which shows that the actual efficiency of the algorithm is relatively high.

TABLE 7. Shows the operating time (s) of the traditional method and 4 kinds of similarity algorithms based on a complex network.

Types		The traditional method				4 kinds of similarity algorithm			
		Exact matching	Contains matching	Implicit matching	Mis-matching	NS	Grid	Yeast	PB
Indexes	HPI	5.6540	4.5681	3.9854	7.4501	0.5019	0.1542	0.1812	0.4106
	CN	4.8956	4.2658	3.6857	7.2822	1.8441	0.0519	0.5931	1.1370
	PA	5.6985	5.3654	4.9887	13.281	0.3361	0.0142	0.1586	0.8125
	AA	2.6542	2.3658	1.5874	8.5460	1.0824	0.0245	0.3540	0.9125
	RA	3.6521	3.0554	2.3652	16.642	1.3254	0.4089	0.4752	0.9524
	CI	6.8755	4.5697	3.6858	13.542	1.2843	0.0451	0.4525	0.7158

TABLE 8. Shows the efficiency (%) of the traditional method and 4 kinds of similarity algorithm based on a complex network.

Types		The traditional method				4 kinds of similarity algorithm			
		Exact matching	Contains matching	Implicit matching	Mis-matching	NS	Grid	Yeast	PB
Indexes	HPI	96.00	48.95	18.65	88.00	99.23	62.71	91.94	85.50
	CN	82.56	42.36	23.51	95.15	99.24	62.87	92.02	92.02
	PA	85.00	36.87	20.36	91.19	74.08	58.01	58.01	86.10
	AA	78.58	55.96	11.56	96.34	99.26	62.87	62.87	92.01
	RA	70.61	61.50	23.68	96.70	99.20	62.74	62.74	99.31
	CI	80.00	50.00	20.00	97.00	99.31	62.97	62.74	62.97

TABLE 9. Shows the matching of the traditional method and 4 kinds of similarity algorithm based on a complex network.

Types		The traditional method				4 kinds of similarity algorithm			
		ct mat chin	s mat	licit mat chin	- mat chin	NS	Grid	Yeast	PB
Indexes	HPI	1.000	0.700	0.400	0.000	0.923	0.838	0.919	0.855
	CN	1.000	0.700	0.400	0.000	0.924	0.728	0.920	0.927
	PA	1.000	0.700	0.400	0.000	0.756	0.881	0.880	0.861
	AA	1.000	0.700	0.400	0.000	0.993	0.887	0.873	0.920
	RA	0.800	0.500	0.200	0.000	0.992	0.774	0.874	0.993
	CI	0.800	0.500	0.200	0.000	0.993	0.897	0.861	0.630

Additionally, we analysed the actual efficiency index (AEI) of the algorithm under specific experimental conditions, as shown in Table 8:

Finally, this result of matching of the traditional method and 4 kinds of similarity algorithm based on a complex network is as follows in Table 9:

V. CONCLUSION

For the characteristics of dynamics and differences for C3DP order tasks and C3DP services, an order-driven C3DP task-service network modeling method is proposed: first of all, a multiple complex network models based on C3DP task-service is constructed according to the relationships among different services, different tasks and between services and tasks; Then, on this basis of the description of C3DP task and its definition of constraint structure, it is put forward to a C3DP order task network modeling;Again, on this basis of the description of C3DP service resource virtualization, a C3DP service network modeling method is proposed; Finally, a C3DP Service_Net model example is designed to verify the feasibility of the method.

REFERENCES

[1] Y. B. Seo, Y. H. Yun, and K.-N. Joo, "3D multi-layered film thickness profile measurements based on photometric type imaging ellipsometry," *Int. J. Precis. Eng. Manuf.*, vol. 17, no. 8, pp. 989–993, Aug. 2016.

[2] J.-S. Lee, Y.-J. Seol, M. Sung, W. Moon, S. W. Kim, J.-H. Oh, and D.-W. Cho, "Development and analysis of three-dimensional (3D) printed biomimetic ceramic," *Int. J. Precis. Eng. Manuf.*, vol. 17, no. 12, pp. 1711–1719, Dec. 2016.

[3] L. Zhou, L. Zhang, Y. Laili, C. Zhao, and Y. Xiao, "Multi-task scheduling of distributed 3D printing services in cloud manufacturing," *Int. J. Adv. Manuf. Technol.*, vol. 96, nos. 9–12, pp. 3003–3017, Jun. 2018.

[4] H. Seidgar, H. Fazlollahtabar, and M. Zandieh, "Scheduling two-stage assembly flow shop with random machines breakdowns: Integrated new self-adapted differential evolutionary and simulation approach," *Soft Comput.*, vol. 17, no. 6, pp. 1–25, Oct. 2019.

[5] D. Ouelhadj and S. Petrovic, "A survey of dynamic scheduling in manufacturing systems," *J. Scheduling*, vol. 12, no. 4, pp. 417–431, Aug. 2009, doi: 10.1007/s10951-008-0090-8.

[6] T. Wong, C. Leung, K. Mak, and R. Fung, "Dynamic shopfloor scheduling in multi-agent manufacturing systems," *Expert Syst. Appl.*, vol. 31, no. 3, pp. 486–494, Oct. 2006, doi: 10.1016/j.eswa.2005.09.073.

[7] W. Xiang and H. Lee, "Ant colony intelligence in multi-agent dynamic manufacturing scheduling," *Eng. Appl. Artif. Intell.*, vol. 21, no. 1, pp. 73–85, Feb. 2008, doi: 10.1016/j.engappai.2007.03.008.

[8] L. Nie, L. Gao, P. Li, and X. Shao, "Reactive scheduling in a job shop where jobs arrive over time," *Comput. Ind. Eng.*, vol. 66, no. 2, pp. 389–405, Oct. 2013, doi: 10.1016/j.cie.2013.05.023.

[9] P. Cowling and M. Johansson, "Using real time information for effective dynamic scheduling," *Eur. J. Oper. Res.*, vol. 139, no. 2, pp. 230–244, Jun. 2002, doi: 10.1016/s0377-2217(01)00355-1.

[10] H. C. Hwang and B. K. Choi, "Workflow-based dynamic scheduling of job shop operations," *Int. J. Comput. Integr. Manuf.*, vol. 20, no. 6, pp. 557–566, Sep. 2007, doi: 10.1080/09511920601024179.

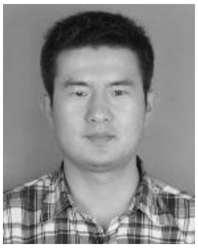
[11] S. Kim, J. Lee, and B. Choi, "3D printed fluidic valves for remote operation via external magnetic field," *Int. J. Precis. Eng. Manuf.*, vol. 17, no. 7, pp. 937–942, Jul. 2016.

[12] M. Zandieh and M. A. Adibi, "Dynamic job shop scheduling using variable neighborhood search," *Int. J. Prod. Res.*, vol. 48, no. 82, pp. 2249–2258, Apr. 2010.

[13] Y. Cheng, F. Tao, L. Zhang, and D. Zhao, "Dynamic supply-demand matching for manufacturing resource services in service-oriented manufacturing systems: A hypernetwork-based solution framework," in *Proc. ASME Int. Manuf. Sci. Eng. Conf.*, 2015, vol. 7, no. 429, pp. 1–7.

[14] F. Tao, J. Cheng, Y. Cheng, S. Gu, T. Zheng, and H. Yang, "SDMSim: A manufacturing service supply–demand matching simulator under cloud environment," *Robot. Comput.-Integr. Manuf.*, vol. 45, pp. 34–46, Jun. 2017.

[15] Y. Cheng, F. Tao, L. Xu, and D. Zhao, "Advanced manufacturing systems: Supply–demand matching of manufacturing resource based on complex networks and Internet of Things," *Enterprise Inf. Syst.*, vol. 12, no. 7, pp. 780–797, Aug. 2018.
[16] Y. Cheng, F. Tao, D. Zhao, and L. Zhang, "Modeling of manufacturing service supply–demand matching hypernetwork in service-oriented manufacturing systems," *Robot. Comput.-Integr. Manuf.*, vol. 45, pp. 59–72, Jun. 2017.
[17] M. G. Raman, N. Somu, K. Kirthivasan, and V. S. Sriram, "A hypergraph and arithmetic residue-based probabilistic neural network for classification in intrusion detection systems," *Neural Netw.*, vol. 92, pp. 89–97, Aug. 2017.
[18] J.-H. Kim and H.-Y. Song, "Hypergraph-based binary locally repairable codes with availability," *IEEE Commun. Lett.*, vol. 21, no. 11, pp. 2332–2335, Nov. 2017.
[19] C. Zhang, B. Sheng, X. Yin, F. Zhao, and Y. Shu, "Research and development of off-line services for the 3D automatic printing machine based on cloud manufacturing," *J. Ambient Intell. Humanized Comput.*, vol. 10, no. 3, pp. 1109–1128, Mar. 2019.
[20] J. Minguella, M. Villegas, B. Poll, G. Tena, J. Calero, M. Ginebra, and F. Korkusuz, "Automatic casting of advanced technical ceramic parts via open source high resolution 3D printing machines," *Key Eng. Mater.*, vol. 631, pp. 269–274, Nov. 2014.
[21] S. Im, Y. Lee, J. Kim, and M. Chang, "A solution for camera occlusion using a repaired pattern from a projector," *Int. J. Precis. Eng. Manuf.*, vol. 17, no. 11, pp. 1443–1450, Nov. 2016.
[22] Y. Yasami, "A new knowledge-based link recommendation approach using a non-parametric multilayer model of dynamic complex networks," *Knowl.-Based Syst.*, vol. 143, pp. 81–92, Mar. 2018.
[23] Y. Yasami and F. Safaei, "A statistical infinite feature cascade-based approach to anomaly detection for dynamic social networks," *Comput. Commun.*, vol. 100, pp. 52–64, Mar. 2017.
[24] F. Tao, L. Zhang, K. Lu, and D. Zhao, "Research on manufacturing grid resource service optimal-selection and composition framework," *Enterprise Inf. Syst.*, vol. 6, no. 2, pp. 237–264, 2012.
[25] F. Tao, C. Li, T. W. Liao, and Y. Laili, "BGM-BLA: A new algorithm for dynamic migration of virtual machines in cloud computing," *IEEE Trans. Services Comput.*, vol. 9, no. 6, pp. 910–925, Nov. 2016.
[26] N. M. Ahmed and L. Chen, "An efficient algorithm for link prediction in temporal uncertain social networks," *Inf. Sci.*, vol. 5, no. 331, pp. 120–136, 2016.
[27] Z. Chen, W. Hendrix, and N. F. Samatova, "Community-based anomaly detection in evolutionary networks," *J. Intell. Inf. Syst.*, vol. 39, no. 1, pp. 59–85, 2012.
[28] H. Fanaee-T and J. Gamab, "Tensor-based anomaly detection: An interdisciplinary survey," *Knowl.-Based Syst.*, vol. 5, no. 98, pp. 130–147, 2016.
[29] N. A. Heard, D. J. Weston, K. Platanioti, and D. J. Hand, "Bayesian anomaly detection methods for social networks," *Ann. Appl. Stat.*, vol. 4, no. 2, pp. 645–662, Jun. 2010.
[30] H. Anwar, I. Din, and K. Park, "Projector calibration for 3D scanning using virtual target images," *Int. J. Precis. Eng. Manuf.*, vol. 13, no. 1, pp. 125–131, Jan. 2012.
[31] C. Yin, Q. Xia, and Z. W. Li, "Semantic matching technique of cloud manufacturing service based on OWL-S," *Comput. Integr. Manuf. Syst.*, vol. 7, no. 7, pp. 1494–1502, 2012.
[32] M. Fatehi and H. H. Asadi, "Application of semi-supervised fuzzy c-means method in clustering multivariate geochemical data, a case study from the Dalli Cu-Au porphyry deposit in central Iran," *Ore Geol. Rev.*, vol. 81, pp. 245–255, Mar. 2017.
[33] S. Usuki, H. Kanaka, and K. T. Miura, "Generation and control of 3D standing wave illumination for wide-field high-resolution 3D microscopic measurement," *Int. J. Precis. Eng. Manuf.*, vol. 14, no. 1, pp. 55–60, Jan. 2013.
[34] K. Cheng, L. Wu, X. Yu, C. Yin, and R. Kang, "Improving hierarchical task network planning performance by the use of domain-independent heuristic search," *Knowl.-Based Syst.*, vol. 142, pp. 117–126, Feb. 2018.
[35] K. Janowicz and M. Wilkes, "SIM-DL$_A$: A novel semantic similarity measure for description logics reducing inter-concept to inter-instance similarity," in *Proc. Eur. Semantic Web Conf. Semantic Web, Res. Appl.*, 2009, pp. 353–367.
[36] J. Zhou, X. Yao, Y. Lin, F. T. Chan, and Y. Li, "An adaptive multi-population differential artificial bee colony algorithm for many-objective service composition in cloud manufacturing," *Inf. Sci.*, vol. 456, pp. 50–82, Aug. 2018.
[37] K. Liu, S. Li, X. Qie, Y. Du, R. Jiang, G. Lu, X. Mou, and G. Liu, "Analysis and investigation on lightning electromagnetic coupling effects of a dipole antenna for a wireless base station," *IEEE Trans. Electromagn. Compat.*, vol. 60, no. 6, pp. 1842–1849, Dec. 2018.
[38] F. T. Azadbakht and G. R. Boroun, "Decoupling of the leading order DGLAP evolution equation with spin dependent structure functions," *Int. J. Theor. Phys.*, vol. 57, no. 2, pp. 495–505, Feb. 2018.
[39] C.-L. Zhang, B.-Y. Sheng, F.-Y. Zhao, X.-Y. Yin, and J.-J. Cao, "Modeling and analysis of 3D Printing WS-BPEL business processes based on servicenet," in *Proc. 4th Int. Conf. Inf. Technol. Appl. (ITA)*, 2017, pp. 663–667.
[40] Y. Cheng, D. Zhao, F. Tao, L. Zhang, and Y. Liu, "Complex networks based manufacturing service and task management in cloud environment," in *Proc. IEEE 10th Conf. ICIEA*, Jun. 2015, pp. 242–247.



CHENGLEI ZHANG was born in Linyi, China, in 1985. He received the B.S. degree in mechanical design manufacturing and automation from Hubei Polytechnic University, China, in 2010, the M.S. degree in mechanical design and theory from the Hubei University of Technology, China, in 2013, and the Ph.D. degree in mechanical engineering from the Wuhan University of Technology, China, in 2018.

Since 2009, he has been a Lecturer with the Department of Mechanical Design Manufacturing and Automation, Linyi University. He is the author of more than ten articles. His research interests include cloud manufacturing, 3D printing, and big data.

FEIYU ZHAO was born in Wuhan, China, in 1992. He received the B.S. degree in mechanical design manufacturing and automation from the Donghu College, China, in 2012, and the M.S. degree in mechanical design manufacturing and automation from Wuhan Polytechnic University, China, in 2016. He is currently pursuing the Ph.D. degree with the School of Mechanical and Electrical Engineering, Wuhan University of Technology. He is the author of more than five articles. His research interests include intelligent virtual assembly, cloud manufacturing, and 3D printing.

ZHENQIAN WANG was born in Linyi, China, in 1988. He received the B.S., M.S., and Ph.D. degrees in mechanical design manufacturing and automation from the China University of Mining and Technology, China, in 2018. Since 2009, he has been a Lecturer with the Department of Mechanical Design Manufacturing and Automation, Linyi University. He is the author of more than five articles. His current research interests include 3D printing and mechanical dynamics.