Construction of a cloud-based mold manufacturing system based on JAFMAS

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Abstract: Molds are the basis of manufacturing of other products, and thus have higher requirements and more complex design processes than other products. Therefore, studying the technologies used in mold production is necessary. This paper aims to build a cloud manufacturing system of mold manufacturing enterprises based on the Java-based agent framework for multi-agent systems (JAFMAS). Specifically, according to the operation characteristics of different cloud-based manufacturing enterprises, this paper first made in-depth analysis of the cloud manufacturing and multi-agent technology, and put forward a hierarchical model of cloud manufacturing system based on multiple agents. Then, as per the structure of the agents and JAFMAS, the interaction and collaboration mechanism between agents in the system were analyzed to establish the functions of the cloud-based mold manufacturing system, thereby building a cloud-based manufacturing system for mold manufacturers based on JAFMAS.

1. Introduction
Molding is an important way of manufacturing in production of parts in the modern world. Statistics shows that molding accounts for 60% ~ 85% in manufacturing of parts in the aviation, aerospace, automotive industries and household electronics. In other words, molding plays an important role in modern manufacturing. The mold manufacturing technology has become a major indicator for the manufacturing strength of a country or a region, playing a decisive role in the quality of end products, technological innovation ability and new product development ability. National governments around the world take development of the mold manufacturing industry as a priority in their initiatives to increase their competitiveness [1,2]. Development of the modern mold technology benefits from the advancement of the whole manufacturing, especially the development of modern digital manufacturing technology. As the basis for production of other products, mold manufacturing has a higher standard and entails more complex and more accurate design. Therefore, it is necessary to study the mold manufacturing technology before it is applied to production of other products, as verified by experiences in developed countries [3,4].

2. Current development of mold manufacturing enterprises in China
After more than 70 years of development, great changes have taken place in the molding industry in our country: as globalization and informationization gain momentum in the manufacturing sector, market competition intensifies, with ever fast upgrading of products. These changes pose serious challenges for
the traditional manufacturing sector which features long cycles, high costs, and a complex design and manufacturing process [5,6]. Now, most mold makers use the CAX technology for mold design and manufacturing.

To meet customer needs and enhance precision, we need to use high-precision NCPC, high-speed CNC milling machine, CNC engraving and milling machines and other special processing machines to complete the mold parts processing and manufacturing. Despite the tremendous investment into design and manufacturing software and machines, the utilization rate remains low. In addition, as competition among mold manufacturers increases, the margins become small. Some, in order to get more orders, lowered the quality and reduced the life in response to the lowered margins, leading to losses on the part of the customers, their rivals and the whole mold manufacturing industry. Most mold manufacturers, struggling to survive market competition, no longer care to improve the technology or adopt information technology, let alone to make innovation. Consequently, transformation and upgrading of mold enterprises turn out a distant dream.

Moreover, mold manufacturers are typical make-to-order (MTO) enterprises. Before reception of an order, no details as to the quantity, type, date of delivery and other specific requirements of the customers are known. After getting the order, they must complete the design, preparation, materials procurement, manufacturing, delivery and a series of new product design and manufacturing processes. Given the low repetition rate of orders, they often need to start the processes all over again every time they receive a new order, and manufacturing accidents or short notices will add to the already high pressure in the design and manufacturing line. Some enterprises, without an edge amid the fierce market competition, fail to receive enough orders, and their idle equipment leads to waste of resources; some highly-reputed manufacturers, however, cannot fulfill the large volume of orders due to shortage of equipment or resources, and hence have to refuse some orders. In fact, with the ever-fast upgrading of products and increasing complexity in product design, even manufacturers with great strength find it difficult to develop better molds independently, thus passing up valuable opportunities to improve the mold manufacturing industry.

“Modern industrial molds first” is a conclusion drawn by developed countries in their move to industrial modernization [7]. Nonetheless, this goal is hard to reach because, on one hand, it entails high technical requirements and relies on the expertise of talents, and on the other hand, the cost is so high that any enterprise cannot afford [8]. To upgrade the mold manufacturing industry in China, to rely on the governmental investment or policies will be far from enough.

3. Current development of cloud manufacturing technology

The concept of cloud-based manufacturing was first proposed by Xun Xu at the university of Auckland, New Zealand in a paper titled “From cloud computing to the cloud manufacturing” [9]. That paper probed into the underlying thoughts, architecture and technical aspect of cloud computing in industry applications, analyzed cloud-based manufacturing prototypes and proposed a cloud-based manufacturing system called interoperable cloud-based manufacturing system (ICMS) [10]. To address the interoperability and compatibility issues in product design in one-of-a-kind production (OKP) systems, B. m. Li et al. drew inspiration from cloud-based manufacturing and put forward a model of product data/knowledge based on the STEP standard [11]. In 2013, a new cloud manufacturing project “CAPP - 4 – SMEs” was launched in the EU's seventh framework programme (FP7). The project officially uses the term of “cloud manufacturing” [12]. In 2014, the White House announced a new digital manufacturing and design innovation scheme [13] which was expected to cost $320 million. The scheme set up a network which connects individuals, companies, machineries and factories together, aiming to realize real-time collaboration and online data sharing and analysis. The idea of the scheme resembles the idea of cloud manufacturing, both of which are to realize resource sharing, efficient integration, quality improvement and high efficiency. Wu et al. made an intensive study of cloud manufacturing strategies and its business application at Georgia Institute of Technology, and put forward a cloud-based design and manufacturing (CBDM) model based on cloud computing [14-16].
Now, China needs to consider how to make better use of cloud computing to better coordinate resources in the manufacturing, reduce repeated investments, improve resource utilization, reduce energy consumption and emissions, thereby achieving a service-oriented manufacturing [17]. To reach this goal, a new manufacturing development model is yet to be found.

At the same time, advanced technologies, such as cloud computing, Internet of things, RFID, virtualization technology, service-oriented technology (knowledge service, technology service, for instance), are developing in leaps and bounds. Mold manufacturing, as the basis of all these technologies, is experiencing tectonic changes [16-18].

4. Application of cloud-based manufacturing in the molding industry
Cloud-based manufacturing system management is mainly the management of information. Although the development of network and information technology provides the basis for it, a flexible mechanism is needed to assist management in the distributed, heterogeneous and dynamic environment, and the likely “loose” or “close” linking contexts of mold manufacturing enterprises. Some network management systems in the practical application are likely to cause messes and lack flexibility. Thus, this paper puts forward an information flow management model, which uses a multi-agent system to assist the cloud-based manufacturing system and create a hierarchical framework.

4.1. Constructing the cloud-based manufacturing system
The structure of the multi-agent cloud-based manufacturing system proposed in this is shown in Fig. 1.

![Multi-agent cloud-based manufacturing system](image)

**Fig. 1 Multi-agent cloud-based manufacturing system**

The system consists of three layers: strategy layer, system layer and execution layer, as shown in Fig. 1. The strategy layer is the core business agent in the system; the system layer involves the task agent, refactoring agent, monitoring agent and resource agent; the execution layer involves agents responsible for mold design, mold production and improvement, etc. Every agent is mutually independent and contact between layers, and agents on the same level complete corresponding tasks through collaboration.

The core business agent is responsible for construction and dynamic scheduling of the whole system; the task agent is responsible for general task of system decomposition and assign the subtasks to corresponding executive agents; the reconstruction agent uses the reconstruction algorithm in the circumstances, and determine the combination of system resources and configuration in the current situation; the monitoring agent monitors and collaborates each agent during the system’s operation; the resource agent collects, stores, updates, maintains, and retrieves information about all members’ resources, and schedules all execution agents; the execution agents complete specific tasks, including product design, production, and sales. All agents work independently and complete their missions based on the received information provided by the knowledge base.
4.2. The agents in the cloud-based manufacturing system

The major work of this paper includes designing an agent system, and establishing a corresponding mission planning decision-making model, a behavior model, a knowledge base and a reasoning mechanism according to the core agent’s goal, the state and behavior of the agents.

Highly anthropomorphic, the agent system provides a new way to solve complex problems in artificial intelligence and computer science. Its basic function is to interact with the outside, obtain and process the information from outside and provide feedback. The basic structure of the agent system is shown in Fig. 2. The agent system is a closed system, consisting of a sensing module, a communication module and a monitoring module. It perceives the changes of external environment by the sensing module, and transmits the information to the internal execution module which then processes the information and makes the final decision. Agents in the system interacts with other agents or the outside through the communication module to complete the allotted tasks.

![Fig. 2 Basic structure of the agent system](image)

Messaging communication which deals with the text information of agents is used to realize the communication between the agents.

Again, the cloud-based manufacture system is distributed, parallel and dynamically-changing. Agents in the system need to communicate and coordinate with each other to complete the tasks. Because of the adoption of agile manufacturing and concurrent engineering, the efficiency of the dynamic alliance structure is greatly improved, but it complicates the system. To ensure normal operations of each agent and module, and avoid problems like congestion and deadlocks, we need a strong analysis and design tool, and in this regard, Petri provides an ideal solution.

4.3. Java-based Agent Framework for Multi-Agent System (JAFMAS)

The JAFMAS is used as the platform in this paper to develop the multi-agent cloud-based manufacturing system. One of its advantages is that it does not need to consider the communication methods between the agents and the behavior coordination mechanism, and thereby more attention can be given to the details of constructing the agent system. At the same time, because the system is based on the popular Java language, it is more suitable for constructing cross-platform distributed multi-agent systems.

JAFMAS is developed by the university of Cincinnati. As a kind of multi-agent system application development framework based on Java [19, 20], it provides a general method to develop multi-agent...
systems; through the collaboration mechanism, it allows the developers to ensure the basic internal operations, communication and collaboration services. These services free the developers from the need of rebuilding the coordination mechanism and provides communication, collaboration between the agents.

JAFMAS is developed in JDK1.1 platform and is divided into some distinct layers based on the servers provided by the 16 Java classes on the platform. It provides basic functions like information communication, interaction and equivalent harmonic balancing for the software developers, and develops the system by extending the four types of users. As shown in Fig. 3 [21], a JAFMAS consists of an interface layer, a multi-agent application layer, a social model, a local model layer, and a communication layer. Each layer has a Java class to achieve its functions, the lower layers provide services to the upper layers, and all layers construct the cross-platform distributed system by Java. One key part of the JAFMAS is the user interface layer, the multi-agent application layer, the social model layer, and the communication protocol layer. The communication layer and the social model provide a basic platform for the implementation of multi-agent application. In a JAFMAS, the communication layer that consists of a communication protocol layer and a language layer; supports broadcast communication and monocular communication.

Fig. 3 Structure of a JAFMAS

(1) The user interface layer

With this layer, the user generates the agents to provide relevant classes, assign attributes to the agents, and display the attributes through the relevant canvas class. Users interact with the system via a graphical user interface (GUI), and construct the agents as per their needs that they introduce to the system.

(2) The multi-agent application layer

This layer provides basic abstract classes for inheritance. In this layer, the user needs rewrite some virtual functions in an abstract class. In any multi-agent system, the user needs to define a field agent, a conversation class, and a ConvRule class of the field agent.

(3) The social model layer

This layer provides the Conversation and the ConvRule class, through which the agent collaborates with each other. The Conversation class consists of communication among agents. The requested ResrcProvider preserves the valuable resources that an agent needs and a list of these resources kept by other agents. One agent will respond to the request of resources put forward by other agents.

(4) The local model layer
The local model layer provides a JDBC database access and invoke method.

(5) The communication layer
This layer is divided into two sub-layers — communication language and communication protocol. The communication language defines the Message and Msgqueue based on the KQML language; The communication protocol is provided based on Java RMI monocular communications and the UDP broadcasting class in the group.

MulticastCom is an inherited object from the Java thread class. An agent can have multiple MulticastComs to purchase multiple groups at the same time, receive messages and then respond to requests sent out by other different groups.

In JAFMAS, as per the structure of the agent system, we only need to expand four classes — the Create Agent, Agent, Conversation and ConvRule, if we want to develop the agents. The system can free the users from problems in communication, interaction and coordination.

5. The functional structure of the cloud-based manufacturing collaborative commerce platform of mold manufacturing enterprises
On the basis of research above, the multi-agent cloud-based manufacturing system is constructed, debugged, and tested.

The prototype system manages information and realizes information interaction and sharing between different agents using the KQML communication language. The functional structure of system is shown in Fig. 4.

Fig. 4 The functional structure of the cloud-based manufacturing collaborative commerce platform of mold manufacturing enterprises

The “task decomposition” is completed by the task agent, and the major functions involve task decomposition and task assignment.

One major function of the task decomposition module is to provide data for task decomposition. Its main principle is to accept the order information according to the existing reserve of resources of the
mold manufacturer, and then decompose tasks by processing the information. In addition, task decomposition module also makes breakdown information queries. The task allocation module is mainly to optimize configuration of the mold production resources by the task agents. In the task allocation module, as the structure of the task agent is complex, it finds solutions to current problems by referring to similar cases in the past, which is a referencing method.

“Bid” and “tender” are two major modules of the cloud manufacturing internal enterprise and member enterprises. Through these two modules, the core enterprise agent and execution (member) agents exchange information constantly each other. The core enterprise agent delivers the task message to the execution agent through the “bid” module; The execution agents that participate in bidding will convey information related to their own resources to the core enterprise agent through the "tender" module. The resource agent optimizes related database information timely.

After the task agents receive the tender, the winner agent can be determined by the following function

\[
\min \{k_1 \left( \sum_{i=1}^{m} \alpha_{ir} MC_{ir} + \sum_{i=1}^{m-1} TC_{ir_{r+1}} \right) + k_2 \left( \sum_{i=1}^{m} \beta_{ir} MT_{ir} + \sum_{i=1}^{m-1} TT_{ir_{r+1}} \right) \}
\]

s.t. \( \sum_{i=1}^{m} MC_{ir} + \sum_{i=1}^{m-1} TC_{ir_{r+1}} \leq C \);
\( \sum_{i=1}^{m} MT_{ir} + \sum_{i=1}^{m-1} TT_{ir_{r+1}} \leq D \),
\( k_1, k_2 \) – constants created to the objective function for dimensionless processing;
\( M \) – the quantity of subtasks;
\( MC_{ir} \) — the processing cost of Agent \( r \) for Task \( i \);
\( \alpha_{ir} \) — Designated weight by the task agent;
\( MT_{ir} \) — Processing time of Agent \( r \) for Task \( i \);
\( \beta_{ir} \) — Designated weight by the task agent;
\( TC_{ir_{r+1}} \) — Delivery cost from Agent \( r \) to \( r_{r+1} \);
\( TT_{ir_{r+1}} \) — Delivery time;
\( C \) — Estimated total cost;
\( D \) — Delivery.

The system checks intelligently the inventory of raw materials (components) through the bidding platform, and performs screening according to the relevant information on the platform before providing a quotation for each supplier agent on the bidding platform.

The main functions “inner search” and “web search” are to search the resources. If we can find the optimal combination to fulfill the task by “inner search” in cloud-based system, the “web search” will not be performed; otherwise, the “web search” is performed to find the most suitable enterprise outside the system and invite the enterprise to the organization. This task is completed mainly by the core enterprise agent and the resource agents.

“Database editor” and “Data” update and analyze the situation and workflow of the enterprise to make the system of each agent master the latest information in virtual enterprise. It is mainly performed by the resource Agent, reconstruct the Agent and the do Agent.

"Database browsing" are the main resources query and schedule query function provided to leader and member enterprises, mainly performed by monitoring Agent. In the process of virtual enterprise running, the monitoring agent supervises and adjusts the system resources in the process of production and scheduling; it also solves conflicts between agents, thus playing a coordinating role.

The operation of the system can be divided into the following stages:

1. The core enterprise agent sends a task notice to task agents, such as the type of mold and the required number;
2. The task agent decomposes the task, and sends the information of subtasks as well as the bidding information to the resource agents;
3. The resource agents inquire about information in virtual enterprise resources through the resource database, the execution agents bid for the task according to their own inventory of resources;
(4) The resource agents provide feedback to the task agent according to the situation and resources of the execution agent;

(5) If the task agent finds the optimal resource agent through “internal search”, the task is allocated;

(6) Otherwise, the “web search” is performed to find suitable enterprises outside of the system; these enterprises are invited to the organization, and if they accept the invitation, the reconfiguration agent updates all information.

The cloud-based manufacturing system built on JAFMAS for mold manufacturers creates four underlying base classes — the agent base class, the dialogue base class, the dialogue rules base class and the message base class, and designs the structure of each agent in the system and the operation process on the basis of these base classes; finally, it develops the agent application software by extending the four abstract classes — Create Agent, Agent, Conversation and ConvRule. Realization of the communication and coordination mechanism between agents relies on the JAFMAS framework. THE system is built in the Windows environment installed with JDK. Compilation and implementation of specific procedures are completed in DOS. The client only uses the ordinary web browser. The platform will be trial tested in several mold manufacturing enterprises of Tong Ling to prove its feasibility and efficiency.

6. Conclusion
JAFMAS, as a system development framework, solves problems in communication between agents, reduces the difficulty in development and maintenance of the cloud-based manufacturing system, provides standard and unified manufacturing services on the cloud. The hierarchical structure of the system can overcome the chaotic problems in general system, and improve system flexibility and flexibility greatly.

The distributed and collaborative structure of the system can not only increase the utilization rate of manufacturing resources and shorten the manufacturing cycle, but overcome the shortcomings of existing manufacturing systems, increase the manufacturing efficiency and promote development of the mold manufacturing industry.

This system is especially beneficial for small- and medium-sized mold manufacturing enterprises that are short of resources or manufacturing expertise. This system can reduce the difficulties in design and manufacturing, and enable flexible production and organization, making the enterprise more competitive in the complex and vagarious market.

Acknowledgments
We would like to express our sincere thanks to the Anhui Provincial Natural Science Research Key Program of Higher Education Institutions (Grant No.: KJ2018A0479, KJ2015A197), Anhui Provincial Excellent Young Talents Fund Domestic Visiting and Study Program of Higher Education Institutions (Grant No.: gxgnyx2020101), and Anhui Provincial Top Academic Aid Program for Discipline (Major) Talents of Higher Education Institutions (Grant No.: gxbjZD2020087), for funding this work.

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