Research on Intelligent Manufacturing System Based on Multi-Agent

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Abstract. Agent and Multi-Agent system is one of the main research directions in distributed artificial intelligence. It has been considered that the Agent technology is an important method to build the model of distributed industrial system, the most natural way to design and implement the distributed Intelligent Manufacturing environment, and one of the significant technologies to construct the manufacturing system of next generation. The manufacturing system based on Agent is the specific application of the theory and method of multi-Agent system in manufacturing domain. On the basis of briefly summarizing the technology of Agent and Multi-Agent system, the architecture of Intelligent Manufacturing System based on Multi-Agent is put forward, among which, agent represents the basic processing entity. The scheduling optimization algorithm of Intelligent Manufacturing is provided, which is feasible proved by the result of stimulation experiment. Compared with the traditional artificial scheduling, it has distinct advantages. Finally, the model of communication and negotiation between Agents in the Intelligent Manufacturing System is studied, which utilizes the features of Agent such as autonomy, social interaction, response capability, preliminary capability, etc so that Intelligent Manufacturing System could make distributed decisions. The cooperation of system is completed by communication and negotiation. During the process of interaction, Agent is endowed with a role to meet the demand of flexibility of building models in the complicated process of Intelligent Manufacturing, as well as to construct an extended frame for reusable components.

Keywords: Multi-Agent; Petri net; Intelligent Manufacturing; scheduling optimization; model.

1 Introduction

With the fast development of information technology and intensified economic globalization trend, manufacturing business has to face the increasingly fierce market competition. Shorter products life cycles, faster updating speeds, and individual and diversified demands of customers for products, all of which make the producing modes and manufacturing organization methods of companies gradually turn from product-oriented to customers, demands and services oriented. In order to succeed in

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the competition, companies are in urgent need of distributed net cooperation producing and manufacturing system complete with good flexibility, quick response and fault tolerant ability. The manufacturing system shall fast adapt to the turn of the market in the situation of possessing certain cost benefit, construct manufacturing process quickly and economically based on different products demands, and carry out self adaptive, self organizing, self studying, liberalization and self maintaining for the whole manufacturing process dynamically. The research results of distributed artificial intelligence domain indicate that, the Intelligent Manufacturing System built with Agent technology is the most potential development direction.

Intelligent Manufacturing System (IMS) shall be considered as a complicated large system organically integrating various intelligent subsystems that complete the distributed solution procedure on the basis of exchanging large quantities of materials, energies and information [1]. The Multi-Agent system theory in distributed artificial intelligence (DAI) provides feasible technical support for modeling and realization of Intelligent Manufacturing System, which becomes one of the research hot points in manufacturing domain. Manufacturing process is a typical Multi-Agent questions solution process, and every department (or segment) in manufacturing system is equal to an Agent in the process. Every sub-mission or unit equipment in manufacturing system could be acted and realized by single Agent or well-organized Agent group, and complete the manufacturing tasks together through their interaction and mutual coordination and cooperation. The manufacturing system shall be stimulated as the Multi-Agent system, which makes the system easier to design, reduces the complexity of the system, intensifies the recombination, expandability and reliability of the system, and improves the flexibility, adaptability and dexterity of the system.

The Intelligent Manufacturing System model based on Agent presented in the thesis adopts Agent as the basic processing entity. Agent is mainly related with transition, the feature of which is described by Petri net. In the end, a method based on dialogue mode is put forward to design the communication between Agents, which is checked by coloring Petri net.

2 Agent and Multi-Agent System

So far, there is no unified definition on Agent [2]. We consider that Agent is the object which could finish the given task independently without people's interference. Now the more common view is that Agent should possess three important features, i.e. autonomy, adaptability and coordination. Autonomy means that the agent shall complete the related tasks actively without external interference (human or other software); adaptability refers to that Agent has the abilities of perceiving and adapting to the external environment and self studying. Coordination is an important feature of Multi-Agent system, in which Agents coordinate and complete a task together. Therefore, the capability of Multi-Agent system is not determined by that of single Agent, but by the intelligence showed by mutual coordination between Agents [3]. Agent possesses the basic attributes such as object, knowledge, label, etc, which is composed of functional units like communication module, business processing module, inference module, study module, information transmission, etc. Agent has the feature of Object-Oriented technology, e.g. inheritance, packaging, information transfer, etc, so the Object-Oriented technology could be used to realize the function of Agent [4].

The specific composition structure of Agent is as follows:

(1) Label: a property feature that one Agent differentiates from others in Multi-Agent system, including name, address of Agent;

(2) Object: Agent consistently operates the pursued specific objects that determine the responsibility and obligation of Agent ;

(3) Knowledge: it includes facts and rules stored in the knowledge base of Agent

(4) Communication module: it is responsible for the communication, information receiving and sending and could transfer tasks, operate results and realize knowledge share.

(5) Inference module: it infers and makes decision based on the object, knowledge, ability and latest information of Agent, and affects on information processing and business procession modules. The decisions it makes must be helpful for the realization of the objects.

(6) Business processing module: processes business. As the main body of Agent realizing objects, it is composed by business processing method.

(7) Study module: summarizes the experiences from the operating process of Agent, increases new knowledge for knowledge base, and improves the capability of adapting to the changeable environment.

Multi-Agent system is composed of a group of Agents distributed in logical or physical positions [5]. The Agents share resources through network, and compose an organized group to complete common task. It is generally considered that Multi-Agent system is especially suitable for the applications based on space, time or function to disintegrate and divide. Adopting Multi-Agent system in these applications will bring the following advantages: (1) the operating speed will be faster due to the parallelization of processing; (2) the demand for communication band width is low because the processing for information is carried out near information source; (3) the error of one Agent will not affect the operation of the whole system, so the system has higher reliability; (4) since the close connection of sense, processing and action, the system has higher response speed.

3 The Structure of Intelligent Manufacturing

Manufacturing industry has experienced all the changes, i.e. manual operation, mechanization, automatization, informatization, integration and intelligence. Industrialization realizes the liberation of human manual labor, informatization further realizes the liberation of human mental work, and intelligent manufacturing has been developed since the recent years. Intelligent Manufacturing, IM for short, is a man-machine integrated intelligent system composed by intelligent machine and human experts, which can carry out intelligent activities such as analysis, inference, judgment, conception and decision-making during the process of manufacturing. The cooperation between human and intelligent machine will expand, extend and partially replace the mental work of human experts during the process of manufacturing [6]. At the same time, it will collect, store, perfect, share, inherit and develop the manufacturing intelligence of human experts [7].

The main types of Intelligent Manufacturing System are: Intelligent Manufacturing System that takes improving manufacturing system intelligence as the object and intelligent robot and Agent as the tool; Intelligent Manufacturing System that integrates the modeling, processing, measuring and operating of corporations through Internet; biological Intelligent Manufacturing System that adopts solution procedure for biological problems. At present, the distributed network IMS model based on Agent is mainly adopted [8], the architecture of which is illustrated in Figure 1. On the one hand, each manufacturing unit is endowed autonomy by Agent to become the entity with perfect functions and autonomy independence; on the other hand, the system is endowed with self organization capacity through the coordination and cooperation between Agents.

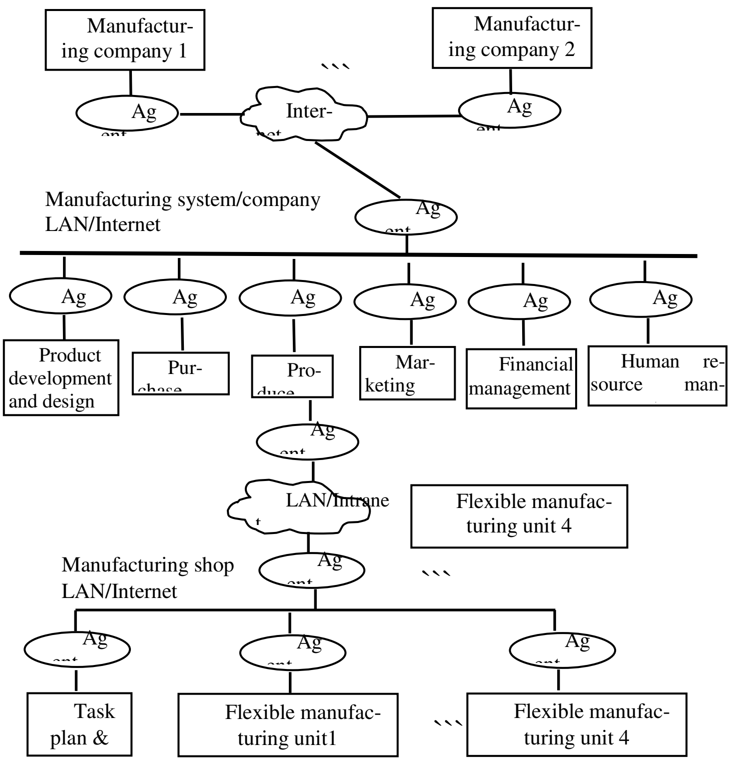

Fig. 1. Network model block graph

When Intelligent Manufacturing System integrates the intelligent machine and human on production site, it shall use all knowledge activities, and flexibly centralizes all activities such as order, design, produce and sales of the company through knowledge base, database, computers and communication network in order to improve the overall efficiency. View from the whole manufacturing process, the segments of order, design, produce and sales are functional independent from each other, and their solution procedures are quite different. The functional subsystems of each segment independently complete manufacturing sub-tasks as well as coordinate with each other. Therefore, inside the manufacturing company, the whole manufacturing process from design to sale is a typical solution procedure for Multi-Agent questions. In order to improve the adaptability of manufacturing system to the state changes from inside to outside, the general structure design of Intelligent Manufacturing System shall obey the open principles, which are showed as: ① openness of the task: the task could be input and processed at any time; ②openness of the system: the system shall hold the changes from interior system (e.g. Malfunction), and accept the interference from outside (e.g. the configuration that changes physical equipments); ③openness of solution procedure: the solution procedure shall accept the changes of information and knowledge.

In order to realize the openness of the above three aspects, distributed structure is resorted to in the Intelligent Manufacturing System, which endows every component entity and subsystem of the system with larger autonomy to form the intelligent autonomous agent. Intelligent autonomous agent is connected with computer communication network by means of intelligent nodes, which are equal in logic (no direction control relations between each other), dispersive in physic and independent in function. The nodes have the loosely coupled relations [9], which contact each other by transferring messages. Based on the common communication language, they coordinate and cooperate to complete the manufacturing tasks.

4 Scheduling Optimization of Intelligent Manufacturing

The scheduling model of the research is: production workshop needs to process multiple components, each of which has many processing methods; a production plan shall be made not only to decide a processing method for each component, but also to ensure the shortest production cycle of the whole shop. During the modeling process, in order to meet the scheduling objects, some complements are made on the basis of the standard hypothesis of the previous scheduling:

(1) Processing in advance is not allowed for any components.
(2) All components could be processed at zero time [10].
(3) Every procedure has specified working contents and processing time.
(4) When a component is finished processing in one machine tool, it will be sent to next machine tool in the processing method immediately. The time for delivery shall be omitted.
(5) The mechanical processing auxiliary time for different procedures is different, which is included in mechanical processing time.
(6) The delay time of workers and robots shall be neglected [11].

Scheduling object:

$$\text{Minimize } Z$$

Constraint condition:

The last procedure in h processing method of component i,

$$T_{ihjk} - H(1 - X_{ih}) \le Z \tag{1}$$

Not the last procedure in *h* processing method of component *i,*

$$T_{ihjk} - T_{ih(j-1)g} + H(1 - X_{ih}) \ge t_{ihjk} \forall i, j, k, h, g, \quad j \ne 1 \tag{2}$$

The first procedure in *h* processing method of component *i (j*=1*),*

$$T_{ihjk} + H(1 - X_{ih}) \ge t_{ihjk} \quad \forall i, j, k, h, \tag{3}$$

There are procedures in *h* processing method of component *i* and *q* processing method of component *p* processed on the machine tool equipment *k*,

$$T_{ihjk} - T_{pqjk} + HY_{ihjpqsk} + H(1 - X_{ih}) + H(1 - X_{pq}) \ge t_{ihjk} \tag{4}$$

$$T_{pqsk} - T_{ihjk} + H(1 - Y_{ihjpqsk}) + H(1 - X_{ih}) + H(1 - X_{pq}) \ge t_{pqsk} \tag{5}$$

For all components, only one processing method is chosen,

$$\sum_{h} x_{ih} = 1 \tag{6}$$

Any processing method of component *i* and component *p* need to use machine tool equipment *k,*

$$-x_{ih} + \sum_{q} Y_{ihjpqsk} \le 0 \tag{7}$$

$$-x_{pq} + \sum_{h} Y_{ihjpqsk} \le 0 \tag{8}$$

Any procedure in *h* processing method of component *i,*

$$T_{ihjk} \ge 0 \tag{9}$$

There are procedures in *h* processing method of component *i* and *q* processing method of component *p* processed by worker *w*,

$$T_{ihjk} - T_{pqjk} + HY_{ihjpqsk} + H(1 - X_{ih}) + H(1 - X_{pq}) \ge t_{ihjk} \tag{10}$$

$$T_{pqsk} - T_{ihjk} + H(1 - Y_{ihjpqsk}) + H(1 - X_{ih}) + H(1 - X_{pq}) \ge t_{pqsk} \tag{11}$$

The same robot in different working time slice should meet,

$$[b_k, b_{k+i}] \cap [b_e, b_{e+i}] = \Phi \tag{12}$$

If the h processing method of component i is chosen under the constraint conditions (formula 1 and formula 6), the objective equation in formula (1) will be used to confine the completion time of the last procedure in the processing method; constraint condition (formula 6) ensures that only one processing method of each component is selected; constraint conditions (formula 2 and formula 3) make sure that for one designated component, the procedure j-1 processed on machine tool g is prior to the next procedure j processed on machine tool k, meanwhile, it explains the working sequence of robots; constraint conditions (formula 4 and formula 5) guarantee that two different procedures cannot be processed on the same machine tool at the same time, and any machine tool cannot process more than one procedures at any time; constraint condition (formula 4) indicates that the s procedure in q processing method of component p is processed prior to the j procedure in h processing method of component i on the machine tool k, and constraint condition (formula 5) shows the opposite processing sequence; in the meantime, when only one processing method of each component is chosen, this precedence is ensured by constraint conditions (formula 7 and formula 8). Constraint conditions (formula 10 and formula 11) guarantee that two different procedures cannot be processed by one worker at the same time and any worker cannot process more than one procedure at any time; constraint condition (formula 12) ensures that the working time of any one robot cannot be intersected [12].

The scheduling algorithm is showed as follow:

Step 1: Calculate the ideal start time of processing for all procedures

Suppose a_k=0, P_w=0, R_r=(0,0), r_n=0

$R_u = L_{i(j-1)} + r_{i(j-1)} + t_{i(j-1)k} + U_{i(j-1)}$ (i=1, 2,…,n and j=2,…,J_i)

Step 2: If there are non-scheduling procedures in procedure set, the non-scheduling procedure ranked the first shall be taken out from the set, and then turn to step 3

If not, suppose makespan = max (F_i) (i = 1,2,…,n)

Step 3: $L(k,1) = \max\{a_h, P_w, r_{ij}\}$

$L(k,2) = L(k,1) + L_{ij}$

If $(L(k,1), L(k,2)) \in R_R$, adjust $L(k,1)$ and $L(k,2)$

$U(k,1) = L(k,2) + t_{ijk}$

$U(k,2) = U(k,1) + U_{ij}$

If $(U(k,1), U(k,2)) \in R_R$, adjust $U(k,1)$ and $U(k,2)$

$f_{ijk} = U(k,2)$

Step 4: Suppose $C_{ij} = \min(f_{ijk})$

If $j = J_i$, $F_i = C_{ij}$

If not, calculate $r_{i(j+h)} = r_{i(j+h)} + (C_{ij} - r_{i(j+1)})$, ($h$ = 1,2,…,$(J_i - j)$)

Step 5: Suppose $a_k = E_{ij}$, $P_w = C_{ij}$

Combine $(L(k,1), L(k,2))$ and $(U(k,1), U(k,2))$ into corresponding set R_r

Step 6: Check if there are non-scheduling procedures in set S; if there is, turn to step 2.

If not, makespan = max (F_i)

In each generation, the algorithm distributes machine tools and workers to every procedure, and ensures no interference with the working time of robots.

5 Experimental Results and Analysis

We conduct experiment on our scheduling optimization algorithm of Intelligent Manufacturing. Figure 2 is the convergence process of scheduling algorithm in multi-resources workshop; figure 3 is tasks distribution of workers.

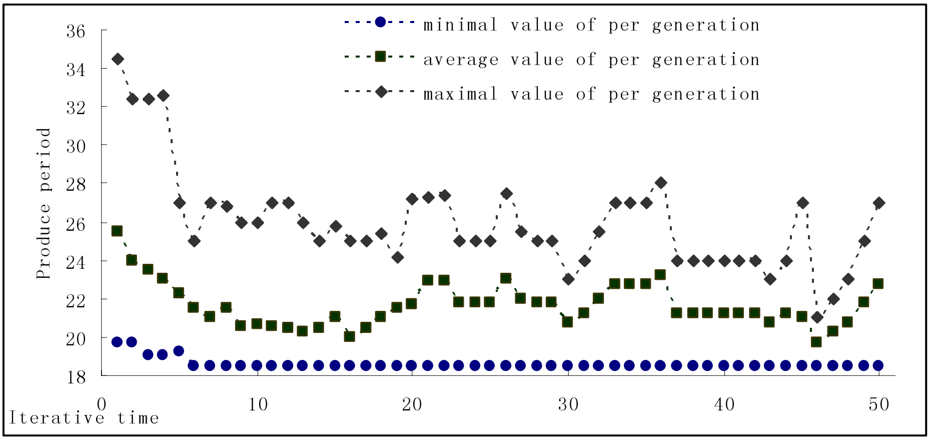

Fig. 2. Convergence process of scheduling algorithm in multi-resources shop

Figure 2 illustrates the convergence process of the algorithm. We can see that, the minimum value of function is decreasing with the evolution of group, and finally, the speed of convergence to extreme value is fast. The average value of objective function in the group is also decreasing with the evolution of group, and tends to the minimum value of the objective function.

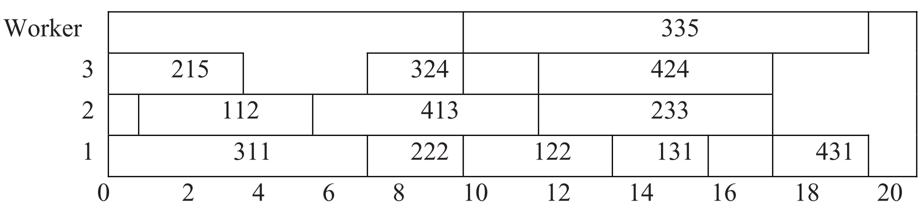

Fig. 3. Tasks distribution of workers

Figure 3 illustrates the corresponding relation among components, workers and machine tools. The abscissa in the figure shows the time of components processing, while ordinate indicates workers. A square with three characters stands for one procedure: the first character is the number of component, the second is the number of procedure, and the third is the number of machine tool. For example, worker 3 with the first work “215” means he processes the first procedure of component 2 on the fifth machine tool, and the man-hour shall be obtained from abscissa. The time from processing start to finish shall be checked from abscissa, in the same way, the final completion time of each component shall be obtained. From this figure, it is easy to count workload of each worker.

6 Conclusion

The thesis makes thorough research on Intelligent Manufacturing System. Considering the features of manufacturing system, we conclude the definition and structure of Agent and discuss the applications of Agent technology in manufacturing system. On the basis of multi-technique scheduling problem, we study the constraint of machine tools, workers and robots in production workshop scheduling problem for the first time. The thesis also studies the production workshop scheduling problem and gives the algorithm and results of scheduling. The stimulation result proves the algorithm is feasible. Compared with traditional artificial scheduling, it has distinct advantages.

In the thesis, the manufacturing system modeling and processing model based on Agent have the following features: compared with general Petri net model, the processing entity Agent has the features of autonomy, response capacity and activity. The cooperation is completed through the interaction and negotiation between Agents, thus the consistency of functions could be guaranteed. Meanwhile, the distributed feature of processing entity Agent can meet the geographic distribution in supply chain of virtual companies. In addition, because of the close connection with Petri net, it can stimulate and evaluate the performance of system, as well as carry out consistency inspection on associated rule in knowledge base.

The future focal point of the research should be on this basis and in accordance with the purpose of the research to reasonably divide the granularity of Agent in manufacturing system, establish the deep relation between Agents, and realize high-precision coordinating work of Multi-Agent. In the course of research, Internet and Intranet technology shall be fully used, especially the inherent distributed computing environment such as Web, distributed object technology, XML, etc. The combination of Agent technology and computer network is the fundamental way to realize network Intelligent Manufacturing and global manufacturing.

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