An Adaptive Process Planning Method Based on Features and Intelligent Agents for the Manufacturing of Large-Scale Parts

Changqing Liu1, Yingguang Li1*, Wenyao Shao1, Weiming Shen2

1 College of Mechanical and Electrical Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing, 210016, China. livingguang@nuaa.edu.cn, liuchangqing@nuaa.edu.cn
2 University of Western Ontario, London, Ontario, Canada wshen@ieee.org

Abstract—Process planning plays an important role for ensuring machining quality, reducing production cost, and shortening leading time. Since there are many uncertainty factors for manufacturing resources in a changing manufacturing environment, especially for small batch manufacturing of large scale parts requiring long process planning time, manufacturing companies are facing significant challenges on process planning of such large scale parts. In order to address this issue, this paper proposes an adaptive process planning method based on machining features and intelligent agents for the manufacturing of large-scale parts. Machining features are used as the carrier of manufacturing knowledge, which provides basis for process planning. Intelligent agents are used to respond to the changing of manufacturing resources. When the manufacturing environment changes, intelligent agents can sense the changes and make decisions in real time. The proposed process planning method can adapt to the changing manufacturing environment and can also shorten process planning time.

Keywords—Adaptive process planning, Machining feature, Intelligent agents, large-scale parts

I INTRODUCTION

Manufacturing of large and complex equipment is characterized by multiple varieties and small batches, e.g., in the aviation manufacturing industry, where a manufacturing facility needs to produce large components and parts for both regular production and new product development. In such manufacturing environment, there are many uncertain factors for manufacturing resources. The changes of manufacturing resources lead to the change of process planning. A survey in some Chinese aircraft manufacturing enterprises shows that about 50% parts require process re-planning due to manufacturing resource changes.

Process planning is a key step shifting design intent to the physical part, which plays an important role for ensuring machining quality, reducing production cost, and shortening production cycle. Changing manufacturing environment makes process planning more difficult. A robust process planning system should have the ability of responding to changing manufacturing environment rapidly so as to adapt to the uncertainty of manufacturing environment. And the result of the process planning should be flexible, so that it can respond to the change of manufacturing environment with as little rework as possible.

The existing process planning methods for the uncertain manufacturing resources are mainly based on STEP-NC [1-4], Function Block (FB) [5-8], agents [9-12], and their combinations.

STEP-NC-based process planning is a distributed process planning method, which provides a certain basis for the intelligence of computer numerical control (CNC), because STEP-NC information model has high level information of geometry and process [13]. STEP-NC based process planning is realized by off-line process planning and on-line process planning. The definition of feature geometry and process information is made by off-line stage, and the tool path generation and movement interruption are executed at the on-line stage.

Function Block (FB) is an international standard IEC61499 in the control field, which has relatively mature data and event-driven mechanisms [14]. Wang et al. [15] applied Function Block to realize distributed process planning for the first time. Different machining features are related with different FBs, which define the manufacturing strategy and tool path respectively, and the process is optimized based on the characteristics of machine tools, so the FB of the same machining features may generate different tool paths in different machine tools.

Agents can make decisions autonomously, which is suitable for building a loosely coupled distributed system [16, 17]. Agent technology is a promising candidate for realizing intelligent factory. Manufacturing resources and products can be represented as agents, and they can sense themselves and make decisions immediately. Coordination policies are also widely researched to support agent based decision making [18]. Agent-based systems are widely used in process planning, production scheduling, and process control [19, 20].
Adaptive process planning methods based on STEP-NC and Function Block lead to much more computational load for the CNC (Computer Numerical Control) system, and it is difficult to adapt to the adaptive process planning of large scale and complex parts. Agent-based process planning has significant effect on the adaptability to the uncertain manufacturing resources. But the existing agent-based process planning approaches lack the ability of responding quickly to the process planning of large scale and complex parts. The fundamental reason is the lack of considering the process characteristics of large scale and complex parts. This paper proposes an adaptive process planning method based on machining features and intelligent agents for the manufacturing of large-scale parts. Machining features are used as the carrier of manufacturing knowledge, which provides basis for process planning. Intelligent agents are used to respond to the changing of manufacturing resources. When the manufacturing environment changes, intelligent agents can sense the changes and make decisions in real time.

The rest of the paper is organized as follows. Section 2 introduces the machining feature based adaptive process planning framework. Section 3 describes the adaptive process planning based on machining features and intelligent agents. Section 4 presents a case study. Section 5 concludes the paper.

II MACHINE FEATURES-BASED ADAPTIVE PROCESS PLANNING FRAMEWORK

By considering the production uncertainty of the machining process of large scale parts, a distributed adaptive process planning method is proposed to realize the flexible and intelligent process planning in this paper. A distributed adaptive process planning framework including preliminary process planning and detailed process planning is presented as shown in Fig.1. Each stage of process planning can be performed on different computer devices, which can realize quick process changes when the manufacturing environment changes.

Process planning can be divided into preliminary process planning and detailed process planning according to the uncertain degree of production, as shown in Fig.2. Process factors which are not affected by manufacturing resources are made in preliminary process planning stage. The manufacturing resource related process factors are made in detailed process planning stage based on preliminary process planning results.

Machining operations and parameters may change because of the uncertainty of machine tool, fixture and cutting tool. The impacting factors of process planning can be divided into three parts based on the analysis above: constant factors along with the change of manufacturing resources, small change factors along with the change of manufacturing resources and factors changing greatly along with the change of manufacturing resources.

The geometries of one type of machining feature and the corresponding machining operation of the machining feature are determined when the type of the feature is defined, which belongs to the constant factors in process planning. Machining feature is the foundation of the process planning, including the determination of machining sequence, selection of machining parameters, generation and adjustment of tool path, the little change factors consist of process, step and the sequence of them. Though the change of machining resource impacts the process, step and the sequence of them, the change is relatively small and can be adjusted slightly by changing the result of process planning. The factors with apparent changes include machining operations and parameters. The machining operations and parameters vary widely for different machine tools and cutting tools because of the performance of machine tools and cutting tools are different. The change of machining operations and parameter may cause the change of tool path.

Process planning is mainly made according to factors with small changes or almost no changes in the preliminary process planning stage based on the classification of process factors. The result of preliminary process planning can be reused in different conditions because it is mainly based on the certain factors without the impacting of manufacturing resource. Because machine tools, fixtures and cutting tools are determined, the detailed process planning can be made in the detail process planning stage. Tool path simulation and verification are also needed at this stage. If there are problems in the simulation results, modification will be made in the preliminary process planning stage, such as the modification of geometries.

The process factors are classified by the method of distributed adaptive process planning according to the uncertain degree of the manufacturing resources, and process planning is implemented by steps, which can ensure the flexibility of process planning results, and increase the reusability of the result of the process planning. Each process planning module has the ability to adapt to the changing of production environment in the framework of distributed process planning, which make the process planning system
flexible and intelligent. Process planning can respond to the change rapidly with as little as possible additional work when the manufacturing resource changes.

III ADAPTIVE PROCESS PLANNING BASED ON MACHINING FEATURES AND INTELLIGENT AGENTS

The process planning system is required to have the ability to sense and make decisions for the changing production environment. In the distributed process planning framework, each part needs the independent decision-making abilities. In this paper, an agent-based system for uncertain machining resources is designed for this need.

The collaboration among multiple agents is required to realize the fast adaptive process planning facing the uncertain machining resources. The function based agent design method is adopted in this paper. Each function is designed as an agent, and it is convenient to organize and manage the system. The distributed process planning system proposed in this paper includes preliminary process planning function agent, detailed process planning function agent, manufacturing resource agent and service agent.

The functions of preliminary process planning agents, detailed process planning agents, manufacturing resource agents, and service agents are designed respectively by considering the uncertainty of manufacturing resources, the process characteristics of large scale parts.

The preliminary process planning agents include feature recognition agent, drive geometry generated agent, feature sequencing agent and preliminary process planning result generation agent.

The machining features are recognized based on the holographic attributed adjacency graph and the geometric and attribute information of the part is extracted by the feature recognition agent. The drive geometry is extracted by the drive geometry generated agent based on the feature recognition result and the machining operation of the feature is decided according to the relationship between the feature geometry and the machining process. The feature sequencing agent decides the machining sequences of feature based on the demand of process planning, and generates the generic processes and steps. The preliminary process planning result is generated and saved by an XML file by the preliminary process planning agent, and is transferred to the feature management agent for the following process planning. The preliminary process planning cannot be fully automatic for complex parts because of immaturity of the machining process and feature definition, so human interaction is still required for preliminary process planning.

The detailed process planning agents include machine tool selection agent, fixture selection agent, cutting tool selection agent, cutting parameter selection agent, tool path generation agent, tool path verification agent and detailed process planning result generation agent.

The machine tool is selected by the machine tool selection agent based on the machining requirement and the production condition. The fixture is selected by the fixture selection agent based on the characteristics of geometry and the process requirement. The cutting tool is selected by the cutting tool selection agent according to the machining feature demand for the cutting tool in the result of preliminary process planning and the material of the part.

The selection of manufacturing resource is completed with the help of the communication and consultation between manufacturing resources selection agent and manufacturing resource agents. The manufacturing resource agents include machine tool agent, fixture agent and cutting tool agent.

The machining parameters are selected by the cutting parameter selection agent based on the result of machine tool and cutting tool selection, the material of the part and the geometric structure of feature. Tool path generation agent generates the tool path according to the machining operation, the characteristics of machine tool, the drive geometry and the cutting parameters. The tool path is verified through the tool path verification agent and the suggestions for modifications are proposed for the tool paths which have interferences. The detailed process planning agent manages and organizes the decision results of each agent, and generates the result of detailed process planning, which is organized and identified using features and feature IDs. The suggestions for modifications are proposed through the communication between the detailed process planning agent and preliminary process planning agent when the irrationality of the preliminary process planning result is found. The communication information between the two agents is organized based on features. Basically, the detailed process planning agent can operate automatically, but human interaction interface is still provided for some special situations.

Machining features play an important role for adaptive process planning. As features are defined by a set of geometries which have relative constant topological relation, and are machined by relative machining strategies, i.e. tool path strategies, machining tools, and cutting parameters, and as like. An association relationship is constructed between the geometries of features and the machining strategies. The toolpath strategies and the type of cutting tools are relatively constant, and the machining features can adapt its corresponding cutting parameters based on the association relationship when manufacturing resources change.

Service agents are designed to realize the communication, collaboration and coordination among the manufacturing resource agents and the process planning related agents. The service agents in this paper include directory service agent, ontology server agent, and feature information management agent.

The directory service agent provides the search function of manufacturing resources. All the manufacturing resource agents need to be registered in the directory service agent, so that the basic attribute information can be searched in the directory service agent. The process planning related agents can get the manufacturing resources through the directory.
service agent in process planning, and communicate with the corresponding manufacturing resource agents. The load of the system can be sharply reduced through the directory service agent, because the process planning related agents do not need to know the attribute information of each manufacturing resource, or obtain information by visiting the manufacturing resource agent one by one. The ontology server agent is linked with ontology definition library, and the ontology server agent provides support for the generation of the process planning related agents and the manufacturing resource agents. The attribute and data structure information of the process planning related agents and the manufacturing resource agents can be obtained quickly through the communication with the ontology server agent, while a process planning related agent or a manufacturing resource agent is building. The feature information management agent is linked with process planning result library, and it is used to save, search and obtain the generated results of process planning. The information management in the process of production is regulated and the efficiency of the system is improved through the feature information management agent.

The communication and collaboration among different agents are expressed through the Dooley graph. Two Dooley graphs are shown in Fig 3 and Fig 4, which are used to express the collaborative relationship among multiple agents clearly. The communication method among different agents of the machine selection in the detailed process planning is shown in Table 1.

![Fig. 3. Collaboration of preliminary process planning agents](image)

![Fig. 4. Collaboration of detailed process planning agents](image)

<table>
<thead>
<tr>
<th>Num.</th>
<th>Sender</th>
<th>Receiver</th>
<th>Expression</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Detailed process planning result generation agent</td>
<td>Machine tool selection agent</td>
<td>Request: Decide required machine tools according to the feature information</td>
</tr>
<tr>
<td>2</td>
<td>Machine tool selection agent</td>
<td>Ontology Server agent</td>
<td>Request: Search required machine tools according to the feature information</td>
</tr>
<tr>
<td>3</td>
<td>Ontology Server agent</td>
<td>Machine tool selection agent</td>
<td>Feedback: Machine A, B, and C meet requirement</td>
</tr>
<tr>
<td>4</td>
<td>Machine tool selection agent</td>
<td>Machine tool A agent, Machine tool B agent, and Machine tool C agent</td>
<td>Raise tender: Complete the use of the machine tool depending on the degree of importance</td>
</tr>
<tr>
<td>5</td>
<td>Machine tool agent</td>
<td>Machine tool selection agent</td>
<td>Announce: Machine A and Machine B can be used</td>
</tr>
<tr>
<td>6</td>
<td>Machine tool selection agent</td>
<td>Detailed process planning result generation agent</td>
<td>Feedback: Through the comprehensive balance. Machine A is chosen</td>
</tr>
</tbody>
</table>

### IV Case Study

A prototype system has been implemented in an aviation manufacturing enterprise. A typical aircraft structure part is selected as an example to demonstrate the function and process of the system. Firstly, the 3D digital model of the part is input to the feature recognition agent. The machining features are recognized and an XML file of feature recognition results is output, as shown in Fig 5. The drive geometry and the machining sequence of features are decided by the drive geometry generated agent and feature information management agent respectively based on feature recognition results and knowledge and rules of machining process. The result of preliminary process planning is generated and the XML file is exported by the preliminary process planning agent by reading the results of feature recognition, drive geometry and the machining sequences of feature. The preliminary process planning agent will receive the feedback from the detailed process planning agent. The change will be made by the drive geometry generated agent according to the demand if the drive geometry of feature needs to be changed.

As shown in Fig 6, the feature information is sent to related agents by detailed process planning agent through the communication with the machine tool selection agent, fixture selection agent, cutting tool selection agent and cutting parameter selection agent after the result of preliminary process planning is input into the detailed process planning agent. The machine tool of each process, the cutting tool of each step and the machining parameters of each operation are decided through the consultation mechanism with manufacturing resource agents based on the feature information. The tool path are generated and verified after the manufacturing resource and machining parameters are decided. The detailed process planning agent provides editing function of the result of process planning, for example, adjusting the machining sequences of feature, and proposing changes for the preliminary process planning. The
new results of detailed process planning are generated quickly by rereading the result of preliminary process planning for the generated results of detailed process planning if there are changes of manufacturing resource in the process of production. Each operation result is displayed in the message list dialog box, and the detailed process planning results are displayed in the right side of the dialog box.

The case study shows that the preliminary process planning results and detailed process planning results can be generated by the prototype system, and the preliminary process planning is flexible and can support detailed process planning. The manufacturing resources can be determined by the communication among agents. Therefore, the adaptive process planning system can respond quickly to manufacturing resource changes.

In contrast to the existing distributed process planning method, the advantages are that: 1) The process planning work is made by off line, it does not take the time of machine tools; 2) it can adapt to the process planning of large scale parts which always take a long time for process planning.
I CONCLUSION

In order to address the process planning issues under uncertain manufacturing environments, an adaptive process planning method based on machining features and intelligent agents for the manufacturing of large-scale parts is proposed. Machining features are used as the carrier of manufacturing knowledge, which provides basis for process planning. Intelligent agents are used to respond to the changing of manufacturing resources. Negotiation for manufacturing resource allocation is performed by intelligent agents. A prototype system has been developed to validate the proposed method. When manufacturing environment changes, the intelligent agents can sense the changes and make decisions immediately. Preliminary implementation results show that the proposed process planning method can adapt to the changing manufacturing environment and can also shorten process planning time. Significant efforts are still required to further develop and test the proposed approach, and also make it more practical and robust. Besides, iteration is always required for the process planning of large-scale parts, the interim state of machining features will also be considered in the future work.

ACKNOWLEDGEMENT

The authors would like to acknowledge the financial support by National Science and Technology Major Project of China (No. 2013ZX04001-021).

REFERENCES