Research Journal of Applied Sciences, Engineering and Technology 4(20): 3865-3871, 2012
ISSN: 2040-7467

Submitted: July 20, 2011 Accepted: April 30, 2012 Published: October 15, 2012

Multi-agent System for Process Planning in Step-nc Based Manufacturing

Juan Du and Xianguo Yan
College of Mechanical and Electronic Engineering, Taiyuan University of Science and Technology, Taiyuan 030024, China

Abstract: In order to realize STEP-NC-oriented computer numerical control machining and achieve optimal performance in manufacturing, a multi-agent system for process planning in STEP-NC based manufacturing was designed. By analyzing the characteristic of STEP-NC data model, a manufacturing feature-oriented process planning method was proposed in this study and the distributed artificial intelligence methods, namely collaborative multi-agent was employed to accomplish process planning of part. The proposed multi-agent system consists of three types of autonomous agents, which are global manager agents, planning agents and manufacturing resource agents, respectively. Process planning can be automatically completed by multiple agents' cooperation. Each agent is capable of communicating to each other through improved Knowledge Query and Manipulation Language (KQML). At last, one test part was designed and simulated to demonstrate the capabilities of this research in the study.

Keywords: Manufacturing feature, multi-agent, process planning, STEP-NC

INTRODUCTION

Since the numerical control technique was developed in 1950's there have been many developments, the CNC (Computerized Numerical Control) system has been the core part of the modern manufacturing systems. Today high precision and speed machine are all accomplished using the traditional CNC machine and the complex parts can be machined on the machining center by means of a single set-up or on 5-axis CNC machine tool (Nassehi *et al*., 2006). However, contemporary most CNC machines are still programmed in the ISO 6983 "G and M code" language, which makes many limitations in current CNC machines. First, the language focuses on programming the tool center path with respect to machine axes, rather than the machining process with respect to the part. Second, the standard defines the syntax of program statement, but in most cases leaves the semantics ambiguous. Third, the vendors usually supplement the language with extensions that are not covered in the limited scope of ISO 6983. Now an international effort is being made towards development of a new data model of data transfer between CAD/CAM systems and CNC machines. This new data model, called ISO 14649 (informally known as STEP-NC), employs a hierarchical data structure to specify machining process rather than machine tool motion and it not only tells manufacturing personal hat to do but also describes ow to do STEP-NC prepares the ground for achieving intelligent, integrated and distributed manufacturing. Today, with the globalization of the economy and the increasing heated competition of market, how to realize intelligent, integrated and optimal manufacturing to reduce the production period and cost and achieve high quality and rapid changes in the product variety, have become more paramount.

As a bridge between Computer-Aided Design (CAD) and Computer Aided Manufacturing (CAM), Computer Aided Process Planning (CAPP) plays an important role in integrated and distributed manufacturing system. Traditional process planning methods are low efficiency and have a great obstacle on getting an optimal processing method, which reduce competitive ability of manufacturing facilities in today constantly changing market environment. In order to achieve lower cost and shorter production time and boost competitive ability of market, it is necessary to seek an advanced technology of process planning for this purpose. Multi-agent technology seems to be an excellent candidate to realize the above mentioned goals. This research applies multi-agent technology to facilitate the complex decision-making during process planning. The objective of this study is to develop multi-agent system for distributed computer-aided process planning in STEP-NC based manufacturing environment. This study gives a architecture of multi-agent system and some key issues of realizing agent-based collaborative process planning are also investigated.

LITERATURE REVIEW

Since the first Computer Aided Process Planning (CAPP) was reported in 1965, there have been numerous

Corresponding Author: Juan Du, College of Mechanical and Electronic Engineering, Taiyuan University of Science and Technology, Taiyuan 030024, China

researches about it. Many approaches have been applied to the process planning, including object-oriented approaches (Sormaz and Khoshnevis, 1997; Zhang *et al*., 1999), Genetic Algorithm (GA)-based approaches (Zhang *et al*., 1999; Morad and Zalzala, 1997), neural network-based approaches (Devieddy and Ghosh, 1999; Monostori *et al*., 2000), feature-driven approaches (Wang and Norri, 2001) and knowledge-based approaches (Stori and Wright, 1996). Recently, distributed manufacturing (Sluga *et al*., 1998) and e-manufacturing (Jay, 2003) are investigated by many researchers and agent technology being one type of distributed AI approaches has drawn wide attention. Agent technology approach has also been as one of the effective ways to realize adaptiveness and dynamism of process planning by Zhang *et al*. (1999). An agent is a software program that specifically performs a user-delegated task while possessing characteristics. Instead of being one large expert system, cooperative intelligent agents are being used in developing distributed CAPP system (Park and Baik, 1999; Sun *et al*., 2001; Zhao *et al*., 2000). It uses cooperation and coordination mechanisms built into distributed agents with their own expert system. Each agent in system is responsible for a relatively independent task of process planning. For an effective system, process planning is the most important manufacturing function that needs to be integrated. The most effective strategy to achieve this goal is to develop distributed system architecture satisfying the cooperation of autonomous distributed controllers. Jay (2003) have conceptualized Shop Floor (intelligent shop floor) by using the internet, web and agent technologies. Leung *et al*. (2010) utilizes an Ant Colony Optimization (ACO) algorithm in an agent-based system to Integrate Process Planning and Shop floor scheduling (IPPS). The integration is important to demonstrate the extensibility of the agent-based system for the complex IPPS problems. An agent-based approach has been developed to facilitate the integration of these two functions (process planning and scheduling). In the approach, the two functions are carried out simultaneously and an optimization agent based on an evolutionary algorithm is used to manage the interactions and communications between agents to enable proper decisions to be made (Xinyu *et al*., 2010). Agrawal *et al*. (2009) employs multi-agent system for distributed computer aided process planning problem. In proposed framework, three types of agent have been used, namely, design agent, global manager agent and optimization agent and each agent can communicate to each other through extensible Markup Language (XML).

MULTI-AGENT BASED PROCESS PLANNING FOR STEP-NC COMPLIANT MANUFACTURING

Mnaufcturing features classification: STEP-NC standard, the new data transfer between CAD/CAM system and CNC machines, employs the object-oriented concept of working step. Working step is component unit of process sequence and it corresponds to high-level manufacturing feature and associated process parameters. Manufacturing feature is not only a component element of product part, but also a component unit of machining sequence. In STEP-NC each manufacturing feature holds a set of coupled information about how to fabricate it, such as machining sequence, cutting tool, process parameter and tool path generation logic and so on. Manufacturing features can be acted as information carriers from part design to process planning and CNC manufacturing in workshop. In this study a manufacturing feature-based multi-agent process planning approach was proposed. Manufacturing features should be classified before process planning is carried out. Figure 1 shows some types of manufacturing features of milling processing. They are those shapes, such as step, pocket, slot and hole.

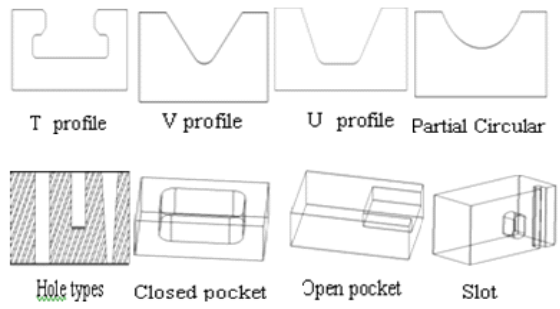

Fig. 1: Part of manufacturing features

Architecture of multi-agent system for process planning: The multi-agent system architecture of process planning is showed in Fig. 2. In this system, the federated multiple agents are used to cooperatively accomplish process planning of STEP-NC based machining. They are classified into three categories according to their functionalities, which are global manager agents, planning agents and manufacturing resource agents, respectively. Manufacturing feature-based product data from CAD are first passed to the process planning system via the web, where the process planning is carried out. When the final process file is generated and transformed into STEP-NC file or XML file, these files are output to Computer Numerical Controllers (CNC) of work floors via the web to realize machining of part.

Planning agents are responsible for planning machining process of each manufacturing feature and generating the whole machining procedures of part. Planning agents include all manufacturing features agent, machining sequencing agent, STEP-NC file generating agent and STEP-NC/XML transfer agent and so on.

Global manager agent cooperates with the planning agents to complete the final process planning of part. The

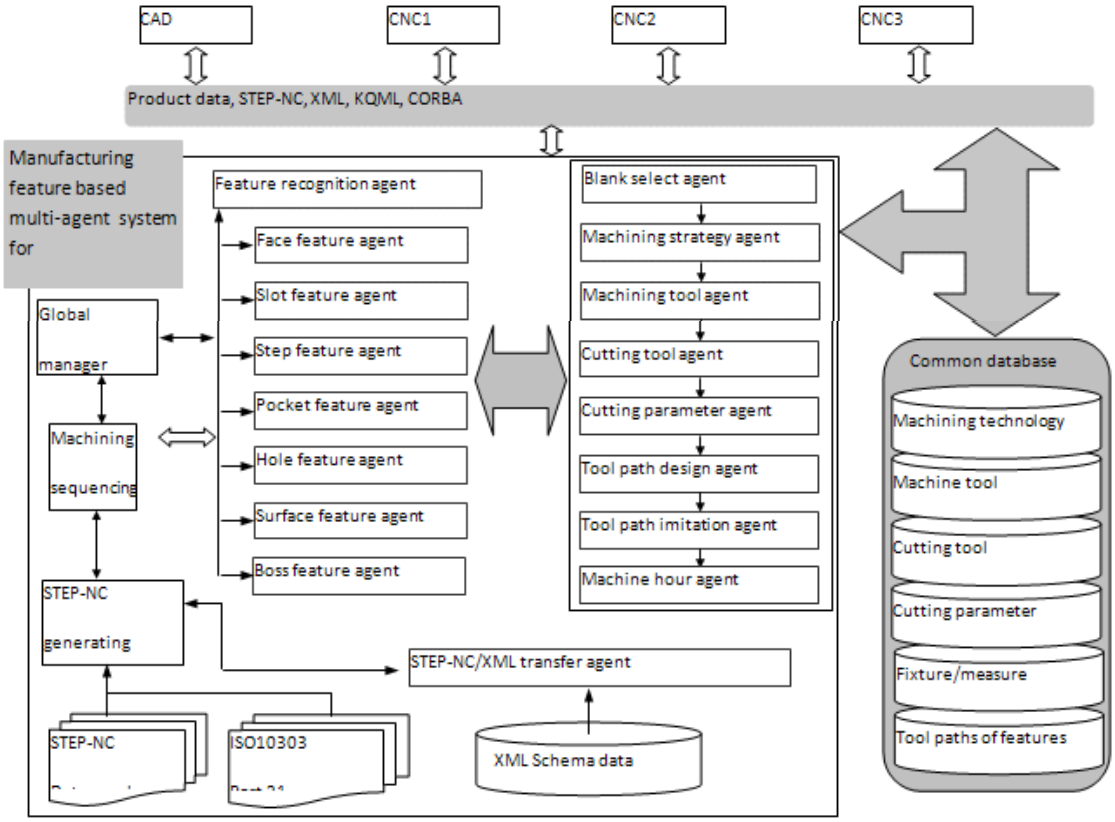

Fig. 2: Architecture of multi-agent system for STEP-NC based process planning

role of global manager agent is to take all the machining processes designed by manufacturing feature agents to the machining sequence agent for generating the final optimal machining sequence of part. Similarly, tool paths of all types of manufacturing features generated by tool path design agent are transferred to global manager agent for assembling whole tool path of the part.

In this study, the process planning of part is achieved by the design unit of manufacturing feature. The purpose of process planning of each manufacturing feature is to tell the manufacturer how the manufacturing feature is fabricated, which involves machining strategy, machining method and selection of manufacturing resource, such as cutting tool, machine tool, fixture and cutting parameters. The selections of manufacturing resource are done by manufacturing resource agents including machining tool agent, cutting tool agent, cutting parameters and so on. Because STEP-NC data model includes not only detailed geometry information of part but also rich process information, such as machining strategy, cutting parameters, cutting tool represented by its id name, tool type, dimensions and so on, every manufacturing resource agent is associated with its resource database. For example, when a cutting tool is selected out by cutting tool agent, its id name and associate cutter geometry parameters are also provided by corresponding cutting tool database. Manufacturing resource database may be located in local computer or on remote web, when it is located on remote web, the data can be acquired via the web.

Workflow of process planning: When the process planning starts, the manufacturing feature based product data from CAD is input into multi-agent system via the web. Each manufacturing feature firstly is recognized from given product data by feature recognition agent. According to the type of manufacturing feature, the corresponding feature agent is activated to ready for process planning. For example, when the feature type is face, the face feature agent is activated and the process planning of feature is carried out by this agent. Each manufacturing feature possesses some key process parameters together with several other non-dominant parameters for its geometry definition. Feature agent passes those parameters to machining strategy agent and all manufacturing resource agents, respectively. According to given feature parameters, the machining method and machining sequence can be decided by the machining strategy agent and manufacturing resources, including the cutting tool, machining tool, cutting process parameters and so on, can be selected by manufacturing resources agents. In order to realize CNC machining of

the part, tool path of each manufacturing feature should be planned. In this study, tool path planning is completed by parameterized design method. Tool path models of all kinds of manufacturing features have been designed in advance and they are stored in tool path database. When the geometry data of manufacturing feature, cutting tool data and process parameters are input into tool path design agent, according to input information and feature type, the tool path design agent will retrieve the tool path model of the corresponding feature from tool path database and generate the tool path of manufacturing feature.

When process planning of one manufacturing feature is finished, the process planning of the next feature will be done. In order to achieve a whole machining procedure file of the part, machining processes of all manufacturing features of the part should be transferred to the machining sequence agent to form a whole machining process sequence of the part. In STEP-NC-oriented machining, the machining procedure file of the part must be converted into STEP-NC file by STEP-NC generating agent. To make the STEP-NC file can be transported correctly by web, a STEP-NC/XML transfer agent is designed to realize conversion between the STEP-NC and XML.

Communication between agents: With the aim of improving communication efficiency and abating load of communication between agents, a method of direct communication is used in this system. This class implements the runnable interface that provides the system with the flexibility to run in a separate thread. According to the need of application itself, we have developed a more flexible communication language based on KQML (Knowledge Query and Manipulation Language). The developed language can express complex facts and tasks and it can be easily understood by the users, i.e. readable and writable. In contrast to other communication languages, which just permits messages composed of function names and parameters, the developed language can be used to assign a task by an abstract description which is independent of the underlying implementation. Therefore, agents can be simply added and replaced without having any knowledge of the internal structures of the existing agents.

The developed one employs message types and message-target to make an explicit expression of message:

```
<message> ::= <message-type>
< message-target> <message-content>
```

The delivered message types are similar to the ones used in KQML in that the message may be a notice, a release, a request, or any other of a set of known behaviors. A message target means the agent to which a message is to be sent. The message-content contains the message text as a string and the text string itself can be either a message text or the data file of cutter location. The class of the message is defined as follows:

```
Class msg - type // the class of message - type
{ ...
Public ;
void Nptice (); // notice information
void Release (); // release information
void Request (); // request information
... }

Class msg –transmission // the class of massage
{
String Mes – transmission // information tyap
String Sender – name : // the name of sender
String Sender - address; // the address of sender
Ctime Transmissions –time ; // transmission time
Int Sender –status ; // Sender status
String Receiver – name ; // the name of receiver
String Receiver – address; // the address of receiver
Int Receiver – states; // Receiver states
String Mes content (); // the message content
}
```

A CASE STUDY

In this section, an instance of part was used to demonstrate how a manufacturing feature-based process plan was generated by multi-agent system. Figure 3 shows a milling part and its physical dimensions.

This part was drawn by CAD system and its corresponding product data was also generated by this system. Before the process planning starts, the product data of part was firstly input the multi-agent system. Manufacturing features, as component elements of part, provide the rich geometry data and process information for part design and machining, so they can be used for information retrieval, data exchange and decision-making support. Manufacturing features based technologies are the foundation of achieving a seamless integration between CAD and CAPP/CAM systems and manufacturing feature-based process planning.

By using these manufacturing features as information carriers from design to process planning and CNC machining, the time and effort for the multi-agent process planning can be significantly reduced. Because all manufacturing features are hidden in product data, how to recognize manufacturing features from product data is a critical issue. There are numerous researches about feature recognition technology. In this study, a feature recognition technology based on macro code was used. Details on how manufacturing features are recognized from macro codes of part are reported separately in author's another study which will be published.

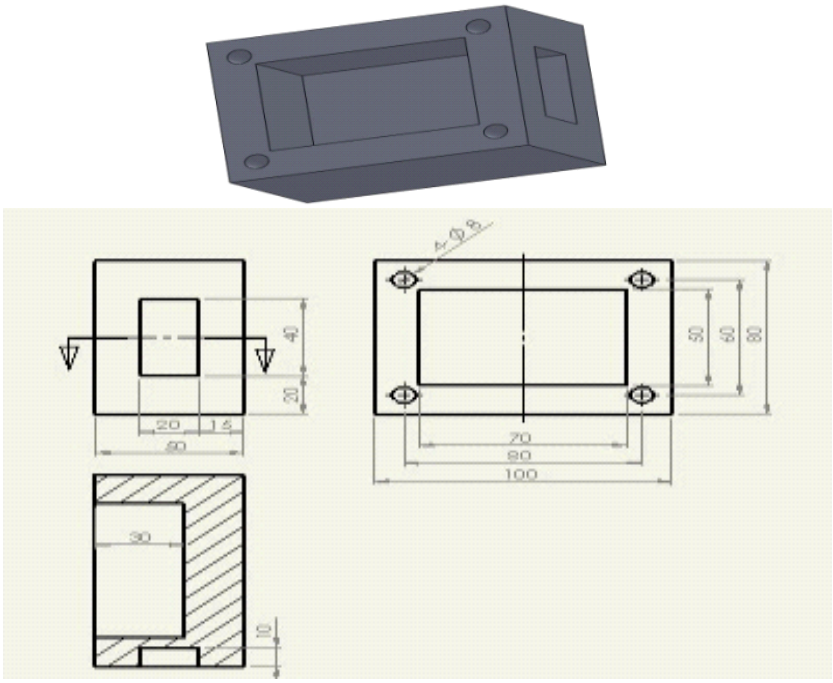

Fig. 3: An example of part

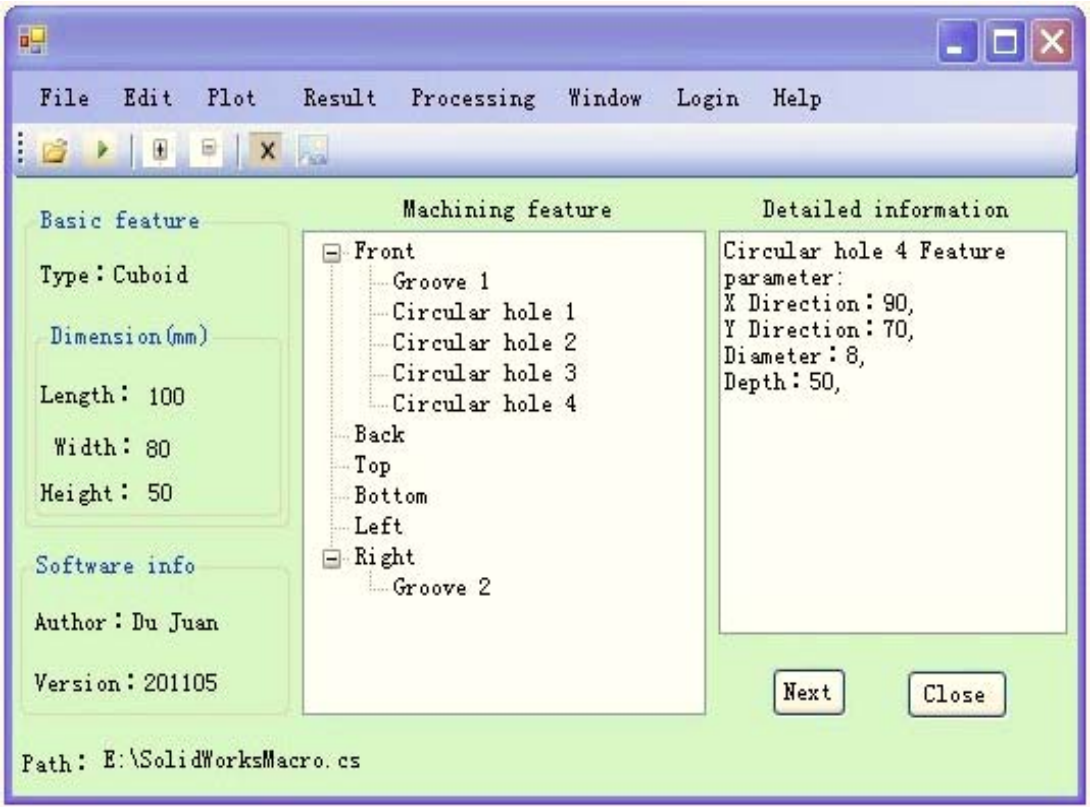

Fig. 4: Recognized manufacturing features of part

According to above feature recognition technology, all manufacturing features can be retrieved from product data. Figure 4 shows recognized manufacturing features of the example of part.

From the Fig. 4, we know three types of manufacturing features are included in part and there are faces, pockets and holes. For each feature, according to its type, geometry data and associate process information, the corresponding feature agent is triggered and to perform process planning of the manufacturing feature.

Process planning of each feature includes machining strategy and machining methods decision, manufacturing resource selection, tool path design and so on. For example, for manufacturing features of face and pocket, there are three machining strategies named as unidirectional milling, bidirectional milling and contour milling, respectively and two types of machining methods, rough milling and finish milling. Machining tool and cutting parameters can be determined by corresponding manufacturing resource agents and specification parameters of machining tool can be retrieved from the associated machining tool databases by resource agent. In order to improve machining efficiency, the bigger cutting tool should be chosen for face milling and rough milling of pocket. In case of finish milling of pocket, the inside round radius of pocket is the key parameter, which determines the diameter of the cutting tool to be used.

To make the part can be machined by CNC machine tool, the tool path of part should be designed by tool path design agent. In this study, tool path generation models of all types of milling manufacturing features have been built in advanced and stored in database. For different feature, it may correspond to one or more tool path generation models. For example, face feature has only one tool path generation model, because the tool path of rough milling is the same as that of finish milling. But for pocket feature, since the machining strategy of rough milling is deferent from that of finish milling, there are two types of tool path generation model (Du *et al*., 2010), named as rough tool path and finish tool path, respectively. Giving type of manufacturing feature and its geometry data, tool data, machining strategy and pre-made tool path generation model, the tool path of manufacturing feature in every working step can be generated by tool path design agent. Figure 5 shows the tool path simulation of rough milling pocket.

After processes of all manufacturing features are planned, the whole process sequence needs to be generated. In order to obtain optimal process sequence, an optimization technology based on elitist selection Genetic Algorithms (GA) was used for this purpose. A detailed technology based on GA for generating optimal process sequence automatically was presented separately in author's another study (Tian *et al*., 2007).

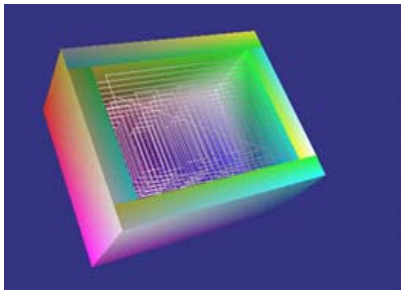

Fig. 5: Tool path simulation of pocket

CONCLUSION

Multi-agent system was developed for process planning in STEP-NC based manufacturing. It can make out an optimal or near-optimal process plan compared to traditional process planning methods. In addition, the time and cost of process planning can be greatly reduced by multiple agents' cooperation. In this study, a manufacturing feature based unit design method was employed, so this multi-agent system has open architecture and is easy to extend. It is expected that this novel approach can achieve the dynamism and adaptive of process planning and can promote the flexibility and performance of machining shop floors in market environment of intense competition.

ACKNOWLEDGMENT

This research was supported by the National Natural Science Foundation of China under Grant No. 50805099, the Natural Science Foundation for Young Scientists of Shanxi Province, under Grant No. 2008021031 and the Top Young Academic Leaders of Higher Learning Institutions of Shanxi Province under Grant No. 20091091 (TYAL). The authors would like to thank the anonymous reviewers for their valuable remarks and comments.

REFERENCES

Agrawal, R., S.K. Shukla, S. Kumar and M.K. Tiwari, 2009. Multi-agent system for distributed computer-aided process planning problem in e-manufacturing environment. Int. J. Adv. Manuf. Technol., 44: 579-594.

Du, J., X.G. Yan, X.T. Tian and L.Q. Liu, 2010. Code conversion technology from STEP-NC-based part programs into G-code for milling. Comput. Integr. Manuf. Syst. CIMS, 16(1): 188-194.

Devieddy, C.R. and K. Ghosh, 1999. Feature-based modeling and neural network-based CAPP for intergrated manufacturing. Int. J. Comput. Integ. Manuf., 12(1): 61-74.

Jay, L., 2003. E-manufacturing-fundamental, tools and transformation. Robot Comput. Integr. Manuf., 19: 501-503.

Leung, C.W., T.N. Wong, K.L. Mak and R.Y.K. Fung, 2010. Integrated process planning and scheduling by an agent-based ant colony optimization. Comput. Indust. Eng., 59: 166-180.

Morad, N. and A. Zalzala, 1999. Genetic algorithms in integrated process planning and scheduling. Int. J. Intell. Manuf., 6: 169-179.

Monostori, L., A. Viharos and S. Markos, 2000. Satisfying various requirement in different levels and stages of machining using one general ANN-based process model. J. Mater. Proc. Techn., 107: 228-235.

Nassehi, A., S.T. Newman and R.D. Allen, 2006. The application of multi-agent systems for STEP-NC computer aided process planning of prismatic components. Int. J. Mach. Tools Manuf., 46: 559-574.

Park, H.G. and J.M. Baik, 1999. Enhancing manufacturing product development through learning agent system over internet. Comput. Indust. Eng., 37: 117-120.

Stori, J. and P.K. Wright, 1996. Aknowledge-based system for machining operation planning in feature based, open-architecture manufacturing. Proceedings of ASME Design Technical Conference, Irvine, CA.

Sluga, A., P. Butala and G. Berver, 1998. A multi-agent approach to process planning and fabrication in distributed manufacturing. Comput. Ind. Eng., 25: 455-458.

Sun, J., Y.F. Zhang and A.Y.C. Nee, 2001. A distributed multi-agent environment for product design and manufacturing planning. Int. J. Prod. Res., 39(4): 625-645.

Sormaz, D.N. and B. Khoshnevis, 1997. Process planning knowledge representation using an object-oriented data model. Int. J. Comput. Integ. Manuf., 1-4: 92-104.

Tian, X.T., J. Du, Z.M. Zhang, J.X. Xu and X.L. Jia, 2007. Non-linear process planning and optimization technique in STEP-NC-based CAPP. Comput. Integr. Manuf. Syst. CIMS, 13(2): 228-233.

Wang, L. and D.H. Norri, 2001. Process planning and control in a holonic manufacturing environment. J. Appl. Syst. Stud., 2(1): 106-126.

Xinyu, L., Z. Chaoyong, G. Liang, L. Weidong and S. Shinyu, 2010. An agent-based approach for integrated process planning and scheduling. Exp. Syst. Appli., 37: 1256-1264.

Zhang, Y., S. Feng, X. Wang, W. Tian and R. Wu, 1999. Object oriented manufacturing resource modeling for adaptive process planning. Int. J. Prod. Res., 37(18): 4179-4195.

Zhao, F.L., S.K. Tso and P.S.Y. Wu, 2000. A cooperative agent modeling approach for process planning. Comput. Indust., 41: 83-97.