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Integration of CAD/CAM using Intelligent Process Planning

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Abstract— **Process planning translates design information into the process steps and instructions to efficiently and effectively manufacture a product. Computer-Aided Process Planning (CAPP) bridges the gap between Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM). CAPP integrates the design representation of CAD systems with the manufacturing process representation of CAM systems. In this paper we describe how we have implemented an Automated Process Planning System that automatically generates a process plan based on the design information, available resources and expert's knowledge. The system is built by creating knowledge base that contains manufacturing knowledge specific rules. The rules cover the whole manufacturing process from raw material selection to finishing operations. The inference engine then selects the appropriate rules and executes them in order to generate a process plan.**

Keywords - Automated Process Planning, Reasoning Rules, Knowledge base, Reasoning Engine

I. INTRODUCTION

Planning & scheduling are the two most important activities involved in any manufacturing organization. Although the terms planning and scheduling are often used together they are two different activities with different objectives. Planning is concerned with what to do and how to do it where as scheduling is concerned with when to do it and who will do it. Identifying set of actions to be performed and the resources required to perform them is part of planning activity. Scheduling on the other hand is concerned with identifying a schedule from a large number of available alternatives. In some cases, it is difficult to decompose planning and scheduling cleanly and in that case we consider them together as a single activity. The objective of Computer-Aided Process Planning (CAPP) system is to bridge the gap between Computer Aided Design (CAD) system and Computer Aided Manufacturing (CAM) System. In this paper we discuss an implementation of CAPP wherein the design of a mechanical part is given in STEP file format and the objective is to automatically generate a process plan for manufacturing it. The automation of process plan involves making inferences based on the decision rules available in the knowledge base. These decisions rules codify manufacturing expert's knowledge in the form of production rules.

The automation of manufacturing process plan from a product design can be seen as a two-stage process. The first stage deals with recognition of the manufacturing features from CAD product description. The recognized manufacturing features serve as the input to the second stage. Here the task is to generate manufacturing process plan by removing manufacturing features from the workpiece block model with certain sequence and accuracy so that a product model is approached. In short, process planning translates design information provided by a design engineer into detailed work instructions to manufacture the part. A detailed work instruction in process planning includes: selection of appropriate machines, tools, machining processes, cutting tools, jigs and fixtures, determination of operation sequences, the generation of NC part programs etc. Hence, process planning involves selection, calculation, and documentation and this task could be very complex, time consuming and also requires great deal of data and experience.

From the preceding discussion it is clear that process planning is an information intensive task which requires significant amount of time and experience. Automated Process Planning system attempts to automate the process planning task by modeling human kind of intelligence. This includes gathering of expert knowledge from individuals (employees, customers and suppliers) and making it available to the entire organization to create a culture of knowledge sharing. Also save time and cost in the transition between design and manufacture. Thus, system provides intelligent functions for automatic generation of Process Plans. It also provides an XML based Data Exchange interface to integrate CAD/CAM system with other life cycle issues such as PDM, ERP etc.

The remainder of this paper is organized as follows. Section II gives process planning overview. Section III surveys prior work. Section IV describes in brief design of Automated Process Planning System developed and Section V concludes the paper.

II. PROCESS PLANNING OVERVIEW

In a traditional manufacturing environment, a process plan is generated by a process planner, who examines a part drawing to develop an efficient and feasible process plan to produce part economically. This manual approach of process planning depends heavily on the knowledge and experience of the process planner to develop accurate, feasible and consistent process plans. In order to prepare new process plan, the process

Deepali Tatkar is currently pursuing a Ph.D. in the Dept of Computer Science and Technology at Goa Unversity planner must be able to manage and retrieve a great deal of data and documents to identify a process plan for a similar part and make necessary modifications to the plan to produce the plan for the new part.

The CAD/CAM integration has several benefits, first the automation of process planning directly following design stage and this result in consistent and accurate production plans. Second, integration reduces the workload on production planners and consequently decreases the planning cost and time. Third, it provides faster responses to change in product design and/or in shop floor status. Fourth, CAPP systems enable the firms to transfer a new product from concept into manufacturing in a short time. All these benefits have a substantial impact on overall productivity of the manufacturing company.

There exist two approaches to the design of CAPP systems [1]. They are the variant and generative frameworks. In variant CAPP approach, a process plan for a new part is created by recalling, identifying and retrieving an existing plan for a similar part and making necessary modifications for the new part. Sometimes, the process plans are developed for parts representing a family of parts called 'master parts'. The similarities in design attributes and manufacturing methods are exploited for the purpose of formation of part families. A number of methods have been developed for part family formation using coding and classification schemes of group technology (GT), similarity-coefficient based algorithms and mathematical programming models. The variant process planning approach can be realized as a four step process; 1. Definition of coding scheme, 2. Grouping parts into part families, 3.Development of a standard process plan, 4.Retrieval and modification of standard process plan. A number of variant process planning schemes have been developed and are in use.

The next stage of evolution is towards generative CAPP. In the generative CAPP, process plans are generated by means of decision logic, formulas, technology algorithms and geometry based data to perform uniquely many processing decisions for converting part from raw material to finished state. There are two major components of generative CAPP; geometry based coding scheme and process knowledge in form of decision logic data. The geometry based coding scheme defines all geometric features for process related surfaces together with feature dimensions, locations, tolerances and the surface finish desired on the features. The level of detail is much greater in a generative system than a variant system. For example, details such as rough and finished states of the parts and process capability of machine tools to transform these parts to the desired states are provided. Process knowledge in the form of decision logic and data matches to the part geometry requirements and the manufacturing capabilities using knowledge base. It includes selection of processes, machine tools, jigs or fixtures, tools, inspection equipments and sequencing operations. Development of manufacturing knowledge base is backbone of generative CAPP. The tools that are widely used in development of this database are flow-charts, decision tables, decision trees, iterative algorithms, concept of unit machined surfaces, pattern recognition techniques and artificial intelligence techniques such as expert system shells. In this paper we have described implementation artificial intelligence techniques in generative process planning framework.

III. PRIOR WORK

Use of Artificial Intelligence (AI) in process planning can be seen as early as 1980 in process planning system GARI [2] developed at the University of Grenoble in France. The system uses a set of reasoning rules as representation of its knowledge base. A part is represented to the process planning module in terms of a set of features like holes, notches etc. which includes geometrical and other manufacturing related information. The system provides the capability of backtracking from any of the intermediate stages of the process planning development to provide necessary revisions. It assigns weights to different pieces of advice at each stage of the process planning development, to resolve any conflicts. Techno structure of Machining (TOM) [3] is a rule-based expert system developed at the University of Tokyo. TOM uses Reasoning rules as its knowledge representation scheme about machining operations, sequencing and geometry of a part. It employs a backtracking search mechanism to generate a process plan.

Hierarchical and Intelligent Manufacturing Automated Process Planning (HI-MAPP) [4] is another AI based process planning system developed by the University of Tokyo. In this system the knowledge base consists of 45 reasoning rules that are classified into 4 categories. There are rules that define process, type of cut, type of machine and rules that can select any other miscellaneous action that the planner wants. HIMAPP then applies the hierarchical and nonlinear planning concepts. Computer-Integrated Process Planning and Scheduling (CLIPPS) [5] system consists of integrated modules namely for automated feature recognition, for determining an efficient and feasible process plan and to generate production schedule plan. The system provides feedback to design and manufacturing engineers to fully evaluate design and ensure that the product can be manufactured in a cost effective manner.

A recent article on the subject of process planning and scheduling [6] gives a good review on integration of rule based process selection. Most of the CAPP systems reported in the literature are developed in Universities and research labs or are proprietary and designed in-house to solve specific process planning problems.

IV. DESIGN OF AUTOMATED PLANNING SYSTEM

The goal of Automated Planning System is to automatically generate a process plan according to design information and manufacturing knowledge available in an enterprise. Its focus however, is on improving work efficiency and quality by Integration, Intelligence and Information Management.

The general architecture for feature based Automated Planning System is shown in Fig.1.The Feature Recognizer module as shown in Fig.2 extracts and translates the design information given in the CAD model into manufacturing information. Input to the Feature Recognizer consists of a STEP file containing CAD models generated by some external solid modelers. The list of manufacturing features presently recognized by the

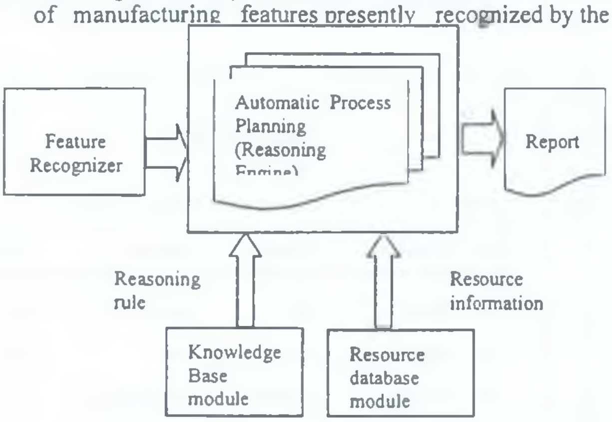

Figure 1. Architecture of Automated Process Planning System

Feature Recognizer includes: Cylindrical Holes/Solids, Chamfers, Fillets & Edge Rounds, Slots & Steps, Pockets, Cones, Tapers & Spheres, Ribs, Threads, Grooves, Bosses, Irregulars and Voids. On completion of the feature recognition task, the Feature Recognizer outputs all the recognized features in a XML file along with their feature parameters as shown in Fig.3.

Automatic Process Planning Module contains manufacturing Knowledge base specified in term of <If-then-else> Reasoning rules. Each Reasoning rule contains detailed set of instruction as to what resources are required to manufacture each feature. Process Planning (Reasoning Engine) module takes in XML file containing recognized features as input, refers it to the Knowledge base and tries to find out which of the Reasoning rules can be satisfied. Knowledge Base module typically manages company specific manufacturing knowledge and experiences. The reasoning rules cover the whole manufacturing process from raw material selection to finishing manufacturing. Resource database module manages all manufacturing resources, including machine tools, cutting tools, measuring tools etc.

The output is a detailed process plan shown in Fig. 5 that typically contains setup operation like how to place and clamp the work piece, nominal machining process operations like drilling, milling with process details such as tool diameter, feed rate, number of passes, and finally finishing operation (if needed to improve the tolerances) along with its process details. The Reasoning rule specified in Knowledge base contains detailed set of instruction as to what resources are required to manufacture each feature. These rules are compiled by the systems personnel by interacting with manufacturing expert.

A. *Reasoning Rules And Knowledgebase*

System divides manufacturing process into six phases. Each phase involves a decision making rules which we call Reasoning rule. The user can define rules according to their own experience and practical situation. Each rule can be represented in the form of if <condition> then <action>. The structure of the Reasoning rules is defined well in separate module called Knowledgebase as shown in Fig.4.

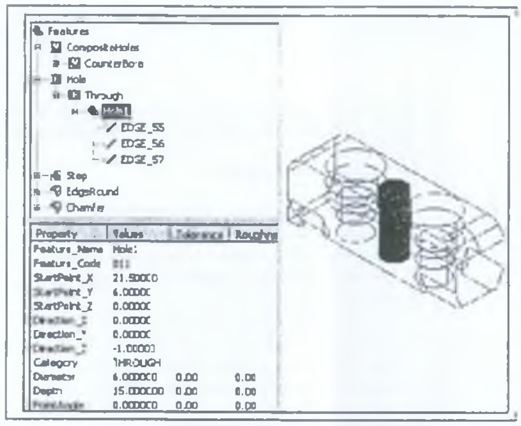

Figure 2. Recognized Feature with non interacting solid and corresponding feature tree with manufacturing information

The user just needs to enter the relevant parameters so as to generate a new rule. Six distinct set of rules identified are: Selection of material, Selection of manufacturing method, Selection of machine tool, Selection of fixture, Selection of sequence of operation and Selection of cutting tool.

Each entity in the selection process is described with attributes. Selection of a particular entity is based on the value of its attribute. For instance, raw material is described by its dimension and material strength. Manufacturing method is decided by feature type - is it a hole or a slot? Different methods will be selected for different feature types along with their parameters and attributes. For example, the parameters of hole include radius, depth, point angle, tolerance, surface roughness, material, and its hardness etc. The machine tool selection depends on the type of operation - is it rough turning, finished turning or drilling? The fixture selection mainly depends on raw material part shape. For example," Bolt", "Tube" and "Block". The sequence selection depends on the order in which sequence of operation need to be carried out, machine tool optimization - shortest time, cost, etc. For instance, the rough turning should be performed before finished turning etc.

In short, Knowledge base consists of logical rules which depict relationships or constraints among different entities involved in manufacturing. Each rule is also associated with a priority. Priority defines the order in which rules will be get selected while generating the process plan. The kind of relationships specified in the knowledge base depends on the understanding and experience of the manufacturing expert. We have provided an interface so that new rules can be inserted and old rules can be deleted or edited. The rules in Knowledge Base may directly influence the final process planning. It means that the quality of these rules will directly affect the results of the process planning. The structure of the reasoning rules is defined in this module and the user just needs to enter the relevant parameters so as to generate a new rule. These rules defined by the user are also easy to modify and change in order to fit to the actual situation.

```xml
<?xml version="1.0" encoding="UTF-8" standalone="yes" ?>
- <dataroot>
- <feature_attribute_gene>
    <id>2</id>
    <Feature_Name>Hole1</Feature_Name>
    <Feature_Code>011</Feature_Code>
    <Dimension_Type>Depth</Dimension_Type>
    <Dimension_Value>15.00000</Dimension_Value>
    <Tolerence>0.00000</Tolerence>
    <Roughness>0.00000</Roughness>
    <StartPoint_X>21.50000</StartPoint_X>
    <StartPoint_Y>6.00000</StartPoint_Y>
    <StartPoint_Z>0.00000</StartPoint_Z>
    <Direction_X>0.00000</Direction_X>
    <Direction_Y>0.00000</Direction_Y>
    <Direction_Z>-1.00000</Direction_Z>
  </feature_attribute_gene>
- <feature_attribute_gene>
</dataroot>
```


Figure 3. Output XML file with manufacturing feature information

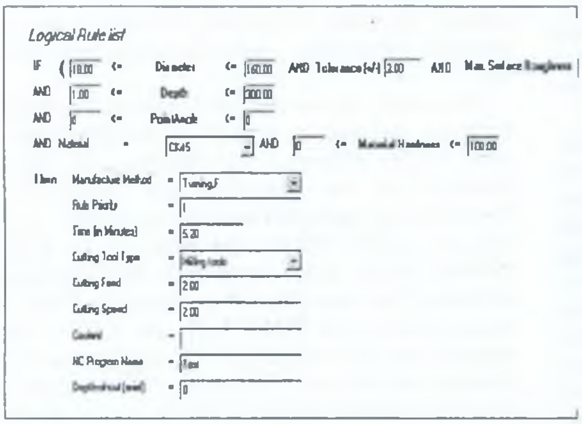

Figure 4. Structure of Reasoning Rules in Knowledgebase

The Resource Database is used to organize and manage the manufacturing resources or the manufacturing phase. Resource base is actually a fact sheet that contains all the material resources available in the enterprise. The structure of the manufacturing resources is defined in the Resource Database module and the user needs only to input the values in the resource record.

B. Intelligent Reasoning Engine

The Automatic Process Planning System works based on generative process planning method. Generative method of process planning has two ways of generating process plan, i.e. reason step by step and reason continuously. Both approaches use intelligent reasoning based on user-defined rule. It automatically develops a process plan depending on the knowledge base, resource database and Feature Information from Feature Recognizer. Automatic Process Planning module calls Reasoning rule from knowledge base and resource information from resource database to generate process planning report. The main heart of system is called Reasoning Engine which is designed for this special role.

The reasoning engine uses the inference mechanism to automatically generate optimal Process plan by applying the Reasoning rules. Loading manufacturing feature information is the first step towards generating a process plan report. Manufacturing feature information is stored in XML file, which is the output of Feature Recognizer

Process Data Report 4/14/2010

PartCode 1 PartName Report 1

OperNo	OperationName	MachineName	MachineType	Time	Cost
10	Turning_R	QT6G	Lathes	28.20	63.13
20	Turning_F	QT6G	Lathes	28.20	63.13
30	Drilling_Dll	Deckel Maho	Five axis milling machine	6.90	14.37
40	Boring_R	SQT200MSY	Horisontal MC	454.00	687.81
50	Reaming	Deckel Maho	Five axis milling machine	8.30	17.29
Grand Total:				525.60 (Minutes)	845.73

Figure 5. Output Process Plan

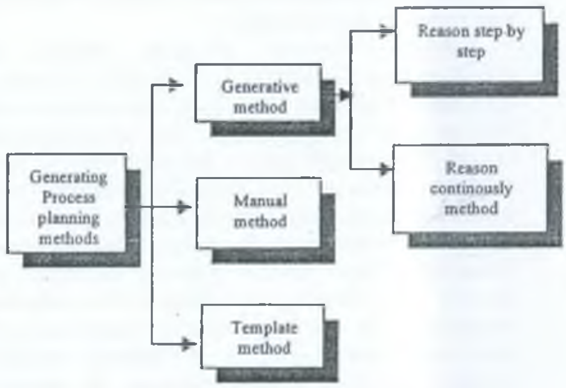

Figure 6. Methods to generate a Process Plan

Module. The job of the reasoning engine is to tell which rules are being satisfied at any given point in time.

Apart from generative process planning method there are two other approaches to generate a process plan, namely, Template Method, and Manual Method as shown in Fig.6. Generative Method automatically builds a process plan using the knowledge saved in the knowledge base and the resources saved in the Resource Database. Manual Method allows building the process plan manually without Knowledge base and Resource database. Template Process Planning is used for generating a process plan report, which has similar characteristics as a saved template. Automatic Process Planning Module provides the process plan edit operation such as insert, delete, modify, move, copy, paste and save.

V. CONCLUSIONS

The paper describes automatic process planning technique that allows manufacturing expert to incrementally specify rules in Knowledgebase and gradually enhance degree of automation. It is observed that the rules in Knowledgebase directly influence the quality of process plan. It is envisaged that over a period of time, with trial and error the system will stabilize and dependence on expert process planner will decrease. One of the practical applications of our system is to estimate the cost of manufacturing the product in design stage itself.

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REFERENCES

[1] Serope Kalpakjian and Steven Schmid "Manufacturing Engineering and Technology, 4th Ed. Pearson Education Asia.

[2] Yannick DESCOTTE and Jean-Claude LATOMBE "GARI: A Problem Solver that Plans How to Machine Mechanical Parts" VOL-2 pages 766-772.

[3] K. Matsushima, N. Okada and T. Sata, "The integration of CAD and CAM by application of artificial intelligence", Annals of CIRP 31, 1(1982).

[4] H. R. Berenji and B. Khoshnevis, "Use of artifial intelligence in automated process planning", Computer in Mechanical Engineering (1986) 45-55

[5] Khalid Aldakhilallah and R. Ramesh, "Computer Technique and Applications of Automated Process Planning in Manufacturing Systems, Computer Aided and Integrated Manufacturing Systems Vol.2, 135-158

[6] D. N. Sormaz, J. Arumugam and C. Ganduri, "Integration of rule-based process selection with virtual machining for distributed manufacturing planning" 61-89, Process Planning and Scheduling for Distributed Manufacturing, Springer Verlag, 2007