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AUTOMATED PROCESS PLANNING IN MANUFACTURING USING KNOWLEDGE MANAGEMENT

Deepali Tatkar[1*], Venkatesh Kamat[2]

ABSTRACT: Two important areas in the life cycle of a product are design and manufacturing. Current interest in manufacturing systems focuses heavily on integrating isolated computer-based systems into a unified system that handles and transforms information to facilitate a smooth production environment. Computer-Aided Process Planning (CAPP) serves as an integration link between design and manufacturing. In this paper we describe how we have implemented the CAPP system. We have used Open CASCADE, an open source CAD kernel to implement feature recognizer. The recognized features are then sent to a manufacturing knowledge management system that automatically generates process plan based on the resources available in the resource base. We have provided an interface to the process planners and the machine tool operators to develop a common Knowledge Base for manufacturing. This Knowledge Base is continuously developed and maintained so that a manufacturing process plan can be automatically generated without much manual intervention or manufacturing expertise.

Keywords: Automatic Process Planning, Knowledge Management, Feature recognizer, Knowledge Base, Resource Base, Reasoning rules, Process Plan.

1. INTRODUCTION

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 the part. This manual approach of process planning depends heavily on the knowledge and experience of the process planner. In order to prepare new process plan, the process planner must be able to manage and retrieve a great deal of documents for a similar part and make necessary modifications to the plan to produce the new part. In this paper we discuss a manufacturing knowledge management framework that attempts to automate the process planning task by modelling a human kind of intelligence.

The automation of the manufacturing process plan from a product design [X08] can be seen as a two-stage process. The first stage deals with recognition of the manufacturing features from the CAD product description. Manufacturing features are typically defined as high level geometric entities representing volumes of material to be removed from the workpiece [SS4Ed]. Feature recognition involves 3-D matching between feature definition and geometric representation of the CAD data model in standard format (e.g. IGES, PDES, STEP, etc.). However, the features which can be recognized are limited and many complex geometric features cannot be identified correctly because of interference among features [Q97, DV09]. The recognized manufacturing features serve as an input to the process planning stage, where the task is to generate manufacturing process plan with a certain sequence of operations and accuracy so that the design information provided by a design engineer is translated 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, selection of jigs and fixtures, determination of operation sequences, the generation of NC part programs etc.

1.1 Prior Work

Automated Process Planning has been an area of research in Artificial Intelligence (AI) for almost three decades. GARI [YJ81] developed at the University of Grenoble in France was one of the early applications

1. New Vision Imaging, NVI House, Tivim Industrial Estate, Mapusa, GOA 403 526
2. Department of Computer Science and Technology, Goa University, Goa, India
* Corresponding author *(e-mail: dtatkar@nvi.co.in)*

of AI in process planning. The system uses a set of production 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 mechanism from any of the intermediate stages of the process planning development to provide necessary revisions. It assigns weights to different pieces of advices at each stage of the process planning development to resolve any conflicts.

Computer Managed Process Planning (CMPP) [TEFLN94] is a generative process planning system that was developed by the United Technologies Research Center for machined cylindrical parts that are characterized by tight tolerances and complex manufacturing processes. The system builds and maintains manufacturing database and based on the description of the part model generates process plan. Techno structure of Machining (TOM) [KNT82] is a rule-based expert system developed at the University of Tokyo. TOM uses production 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) [HB86] is another AI based process planning system developed by University of Tokyo. In this system knowledge base consists of 45 production rules that are classified into 4 categories. These are rules that define process, type of cut, type of machine and rules that can select any other miscellaneous action that the planner wants. HI-MAPP then applies the hierarchical and nonlinear planning concepts. Turbo-CAPP [HR87] is an intelligent process planning system in which a problem solving knowledge is represented as production rules and is stored in three planning layers: layer of facts, layer of inference rules and layer of meta-knowledge. The system starts with extracting geometric entities in terms of surface features from the part description provided by the 2D CAD system. Then based on the features and the qualification data, the system generates sequence operation and NC code.

Computer-Integrated Process Planning and Scheduling (CLIPPS) [KR] 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 [DJC07] 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 lab or are proprietary and designed in house to solve specific process planning problems. Manufacturing Knowledge Management System is designed keeping in view the requirements of manufacturing industry. The remaining sections will give details about system architecture and its implementation details.

2. OVERVIEW OF MANUFACTURING KNOWLEDGE MANAGEMENT SYSTEM

The goal of Manufacturing Knowledge Management 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 key modules of Knowledge Management system are shown in Figure.1.

The Feature Recognizer module 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 model generated by some external solid modeller. The list of manufacturing features presently recognized by the Feature Recognizer includes: Cylindrical Holes/Solids, Chamfers, Fillets & Edges 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.

Automatic Process Planning Module contains manufacturing Knowledge base specified in term of <If-then-else> production rules. Each production 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 production 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 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 production rules 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.

3. IMPLEMENTATION

In this section we shall discuss in detail different modules of the Manufacturing Knowledge Management System that we have implemented as a part of process planning system called Xplano [XPLANO, DVK09].

3.1 Feature Recognition

Automated recognition of features from CAD models has been attempted for a wide range of application domains in mechanical engineering. However, the absence of a clear mathematical formalism for the feature definition has made it difficult to develop a general approach and thus most of these methods are limited in scope. In this work we recognize a class of machinable features expressed in neutral STEP format. Feature Recognition facilitates Process Planning & Manufacturing activities and has been of significant importance in Computer Integrated Manufacturing (CIM). However the emerging paradigm of Agile Manufacturing has imposed additional requirements of "Neutral format" so that Form-Feature information can be readily shared among multiple partners of a virtual enterprise. The Standard for the Exchange of Product model data (STEP) has emerged as the means for neutral form exchange of product related data. For mechanical parts, the description of product data has been standardized by ISO and ISO 10303-21 is informally known as STEP. It is an ASCII file based on Boundary Representation (B-Rep) of solid.
Feature Recognition module is implemented using the Open CASCADE's Geometric Modelling toolkit [OC03]. Each manufacturing feature is coded in C++ using collection of rules [MR00]. For each feature, the entire CAD model is searched. Any feature satisfying the condition/rule is added to the feature database. Also, simultaneously the tree-view giving the list of recognized feature is updated in the 3D Viewer. All the algorithms in Feature Recognition system are implemented in C++ using object-oriented modelling principles [4]. This system takes as input STEP AP203/AP214 file defining geometry and topology of the part. After the module "reads-in" the STEP file, it goes through the file to check whether the file has the required type of shape representation, namely the Advance B-rep Shape Representation (ABSR). If the ABSR shape representation does not exist in the file, it implies that the file does not have topology information which is essential for extraction of features. At this point feature recognition process stops, informing the user that the file cannot be processed further. On the other hand, if there exists an ABSR entity in the file, the features can be recognized from the given topology information within the file and the recognition module continues further. Feature Recognition is done using the Rule based recognition system using the

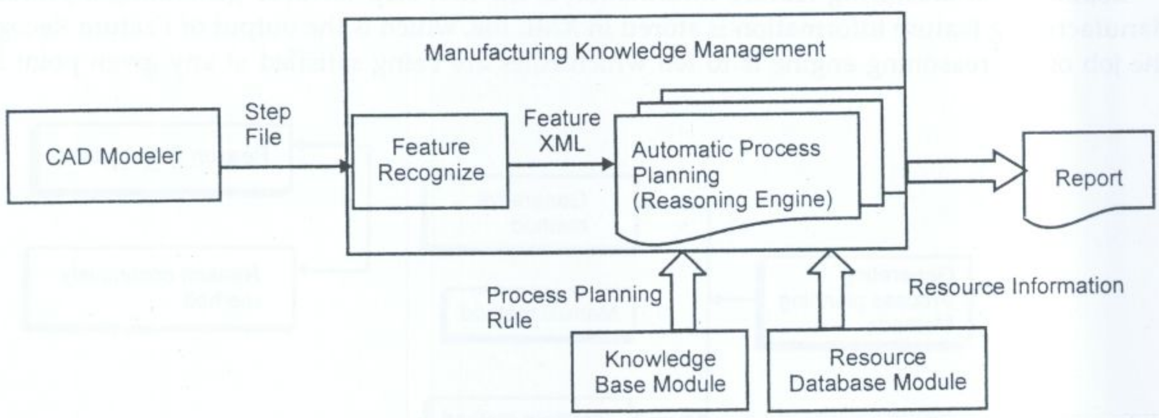


Figure 1.Architecture of Knowledge Management System

Open CASCADE kernel's geometric modeling toolkit. In Rule based system, feature recognition rules are written in IF Then ELSE form. For each feature, the entire CAD model is searched. Any feature satisfying the condition/rule will be added to the Feature Database. Algorithms are written to recognize the different types of features using the Open CASCADE Kernel. The features that the module can recognize at present: Cylindrical Holes/Solids, Chamfers, Fillets & Edges Rounds, Slots & Steps, Pockets, Cones, Tapers & Spheres, Ribs, Threads, Grooves, Bosses, Irregulars and Voids. On completion of feature recognition, it outputs all recognized features in a XML file which includes details on Feature parameters.

3.2 Knowledge, information and Resource management

The Knowledge base module organizes all rules and knowledge available for generating the process plan [BHFH99]. System divides manufacturing process into six phases. Each phase involves a decision making which we call production 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>. Six distinct set of selection 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 rules which depict relationships or constraints among different entities involved in manufacturing. Each rule is also associated with a priority. 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.

3.3 Automatic Process Planning

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

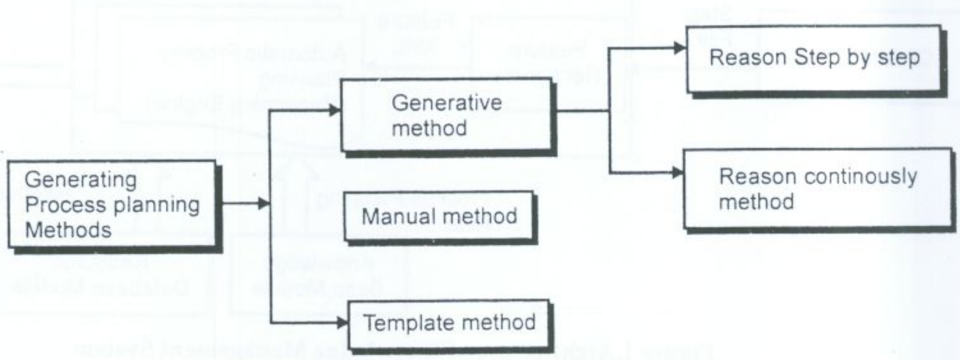


Figure 2.Methods to generate a Process Plan

In case of conflict, i.e. more than one rule is getting satisfied, we use the concept of priority to resolve the conflict. Inference engine goes through reasoning process in step by step order. As shown in Figure 3. below, there are three different approaches to generate a process plan, namely Generative Method, Template Method, and Manual Method. 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. 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. Automatic Process Planning Module provides the process plan edit operation such as insert, delete, modify, move, copy, paste and save. It allows template function to share the process plan information along with user-defined process plan table. User can save process information in different formats.

3.4 Example with Manufacturing Knowledge Management System

The system can be best understood with the help of a working example. First stage involves invoking Feature Recognition Module. Input to the Feature Recognition Module is a STEP file containing the part definition. 3D viewer helps in visualizing the part as well as recognized features

Figure 3(a). shows 3D viewer containing list of extracted features. The top left panel shows the recognized features in tree view form. The bottom left panel shows details of each feature such as dimensions, tolerances, roughness, etc. Figure 3(b). below shows Resource Base module which manages manufacturing knowledge and experience. It is designed such that it can select optimal resources for different operations in part manufacturing. It stores information about raw materials, machine tools, cutting tools, measuring tools etc. It provides search, edit functions, and allows user to define his /her own functions.

Figure 4(a) shows an interface to define a rule in Knowledgebase module. It allows to extract, organize and manage company specific manufacturing knowledge. It also provides user to define rules according to his/her own experience. It also has Edit facility for the knowledge base. Figure 4(b) shows an output from Automatic Process Planning module which is an optimum process plan generated after reasoning process.

4. CONCLUSION

This paper describes Manufacturing knowledge management framework, implemented to automate process planning in manufacturing. The framework 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. Over a period of time, with trial and error the system stabilizes and over dependence on expert process planner reduces.

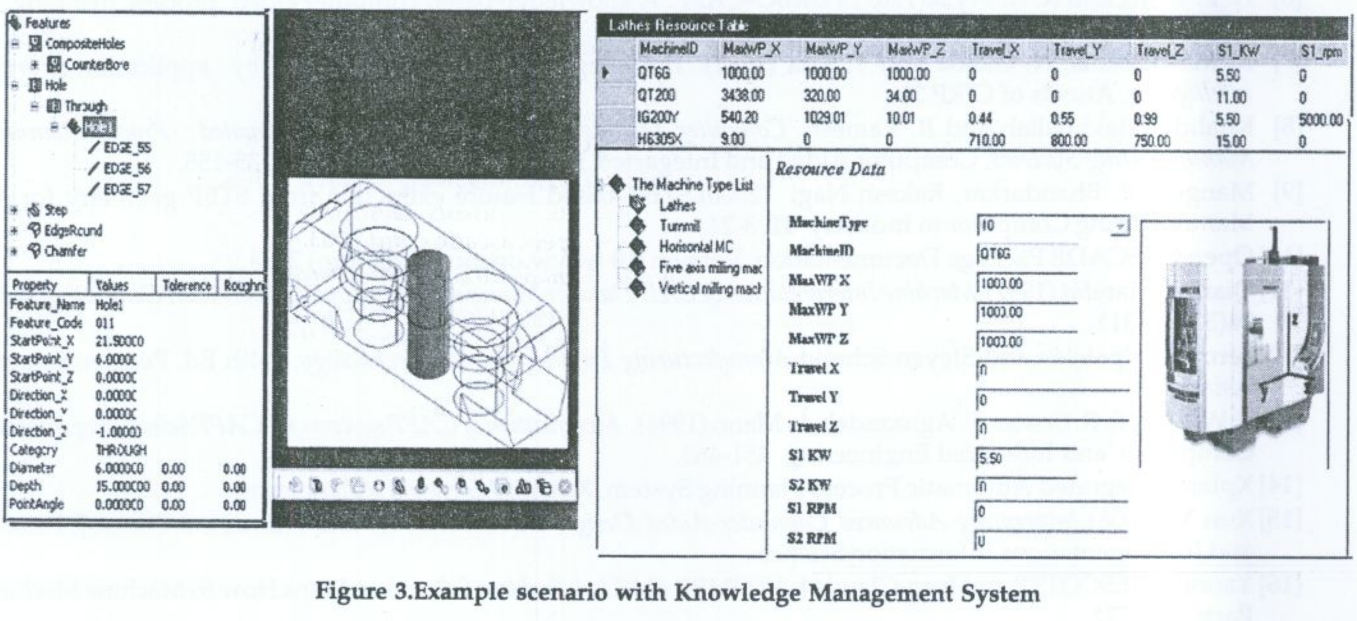
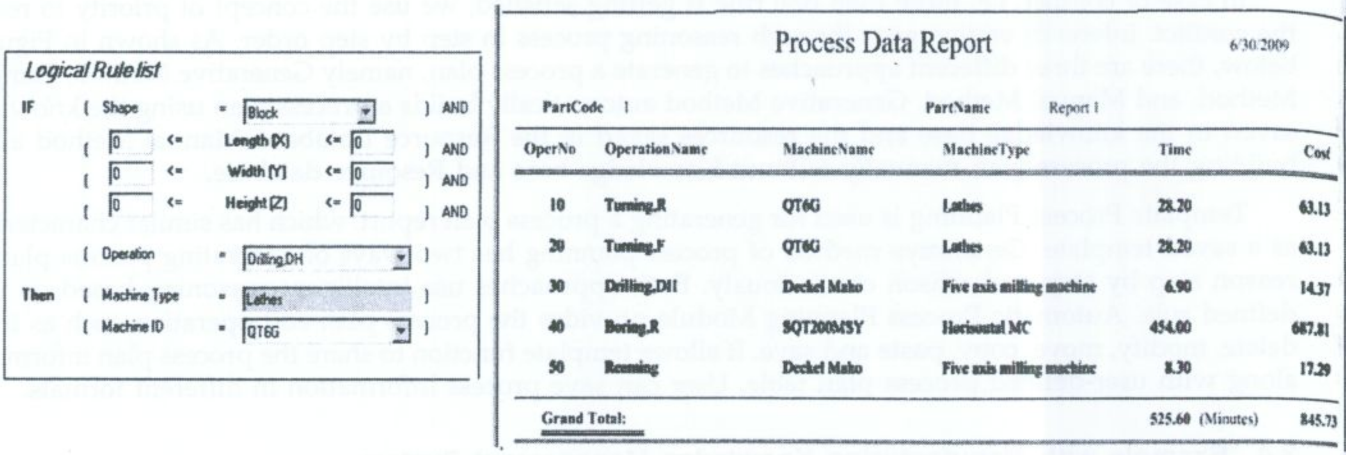


Figure 3.Example scenario with Knowledge Management System



Process Data Report 6/30/2009

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.DH	Deckel Maho	Five axis milling machine	6.90	14.37
40	Boring.R	SQT200MSY	Horizontal 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 4.Example scenario with Knowledge Management System

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