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Application of Novel Knowledge Based Paradigms in Computer Aided Manufacturing Process Modeling

In this paper a knowledge based approach to the computer aided manufacturing process planning (CAPP) is proposed Earlier experiences of authors revealed knowledge acquisition and storage and knowledge based problem solving requirements posed by the decision intensive CAPP. These experiences suggest integration of knowledge based techniques for nonlinear process modeling. The paper is constructed as follows. First, the problems emerged a present day CAP methodologies are explained. Then application of computational intelligence techniques for solving classical CAP problems is analyzed Following this, a new approach to knowledge based CAP based is proposed Finally, the process planning procedure is analyzed and the stages of planning that call for some type of machine learning, inference and uncertainty-handing methodology are identified.

Key words: knowledge based systems, soft computing, computer aided manufacturing process planning (CAPP), machine learning, Petri nets, neural networks, fuzzy reasoning.

1. Introduction

Decision making under computer assistance is the main concern at computer aided manufacturing process planning (CAPP) because of the need to produce software for CAD/CAM and flexible manufacturing systems. In recent years decisive

CAPP was emphasized as a field that has significant potential for productivity enhancement Conventional knowledge based approaches to CAPP have failed to be ultimate solutions that have chance for implementing in real factory environment. The trends in the industry show a growing importance of small batch production. This causes constantly increasing role of flexible manufacturing systems. The efficient use of a FMS calls for CAPP systems, which are able to generate process plan in compliance with the actual demands of their environment. At the same time the process plan must comply with the demands of the production scheduling.

The authors of this paper made an attempt to develop knowledge based manufacturing process planning methodology with the aim of producing problem solving procedures for CAD/CAM systems and FMSs. Hungarian researchers have produced advanced manufacturing process planning systems [2]. Attempt was made at solving problems emerged at computer assisted decision making. The GLEDA system [1] is an example of these efforts. This systems has been successfully implemented at company environment in Hungary. On the basis of the experience gained at that project a new approach has been evolved utilizing new paradigms for development of sophisticated problem solving procedures.

This paper summarizes a new soft computing approach and methodology for the solving of problems emerged at manufacturing process planning with up-to-date methodology. The authors have investigated the application of Petri Net, Fuzzy logic and other knowledge acquisition and representation tools. A special interpretation of high level Petri net formalism together with the object oriented and approximate reasoning paradigms has been involved. The scheduling of the production at a plant calls for process plan variants all of which conform with technological constraints. For that reason the proved concept of the non-linear process plan has been adapted [3].

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2. Criticism of present day CAPP methodologies

The powerful CAD/CAM systems are becoming more and more important for the creative design and planning practice. The computer aided manufacturing process planning (CAPP) is often a missing link between the CAD, CAM and production scheduling elements in integrated design and planning systems. This is because the process planning is a very complex and heterogeneous activity that requires very special methodology. This methodology differs from that used by commercial CAD/CAM systems. The processing of a large amount of information calls for less or more decision support. Excellent tools have been developed for solving geometric processing tasks. For that reason developers concentrate on solving CAPP tasks that call for advanced geometric processing. On the other side CAPP calls for advanced geometric processing, establishing of which in a CAPP system is unreasonably expensive. The only logical solution is realizing a complete CAPP tool kit in CAD/CAM systems.

In the last decade research efforts brought about experiences at adapting advanced problem solving methodology for solving old problems of the manufacturing process planning. Most of the researchers are involved in development of stand-alone manufacturing process planning systems. Obviously, the usual process planning methods are not very well suited to manage decision making in CAD/CAM systems. Separated decision making functions are required. These functions can be attached to some functions of a CAD/CAM or flexible manufacturing system. This demand calls for separate procedures. Various approaches are known for generating the manufacturing process for a part. The early expert systems used backward chaining which started from the ready made workpiece, then operations suitable to achieve this from the blank are sought [4]. The "conventional" expert systems involve knowledge bases, which are too complicated, special and hardly understandable for company personnel. Another popular approach is generating sub-processes for each of the features defined on the part then synthesizing them into a process plan.

A third way is proposed in this paper that follows the thinking of a human manufacturing process planner who conceptualizes a process then elaborates sub-processes for each of the features, finally places the sub-processes into the process concept. The process planning procedures use part data according Fig. 1.

Recently, feature based approaches have been widespread in the geometric modeling. The features make representation of non-geometric attributes possible too. It is logical to define similar entities for the manufacturing process so that similar principles may be applied for geometric and process modeling. In case of these systems the main pre-requisite of involving decision support procedures has been fulfilled. This time only few advanced CAD/CAM systems offer functions for creation and storage of manufacturing process entities. An example is the EUCLID3 system. The manufacturing process is an entity that represents the place of "sequences", "operations" and "cycles" entities in a tree structure. A process is a series of "sequences". A "sequence" is a series of operations performed by a given machine tool with a given set-up. An "operation" is a succession of machining cycles performed by the same tool. Material to remove is an additional entity for process planning. An objective at the development of the PRODES system [8] is also integrating the process planning and the product modeling. The process entities in this system are called as "process features" that are related to the "form features" of the part model. The PRODES system uses special process features for description of manufacturing sub processes attached t o each of the features independently from the method of the manufacturing. This is based on a proved principle [1]. The [9] proposes process sequence, process, operation and path features. The "process" in this concept represents operations that are performed on the same form feature using the same manufacturing process (e.g.Milling). The manufacturing of a part is represented by the process sequence feature.

3. Computational intelligence techniques for manufacturing process planning

The conventional approaches to understanding and predicting the behavior of complex systems, having multiple variable and multiple parameter models with perhaps non-linear coupling, based on analytical techniques can prove to be inadequate, even at the initial stages of establishing an appropriate mathematical model. The computational environment used in such analytical approach is perhaps too categorical and inflexible in order to cope with the intricacy and the complexity of the real world industrial systems. It turns out that in dealing with such systems, one has to face a high degree of uncertainty and tolerate imprecision. Trying to increase precision can be very costly. In the face of difficulties stated above. Prof. Lotfi A. Zadeh proposes a different approach to computation. He separates hard computing based on binary logic, crisp systems, numerical analysis and crisp software from soft computing based on fuzzy logic, neural networks and probabilistic reasoning. Hard computing has the attributes of precision and categorization an soft computing approximation and dispositionality [11].

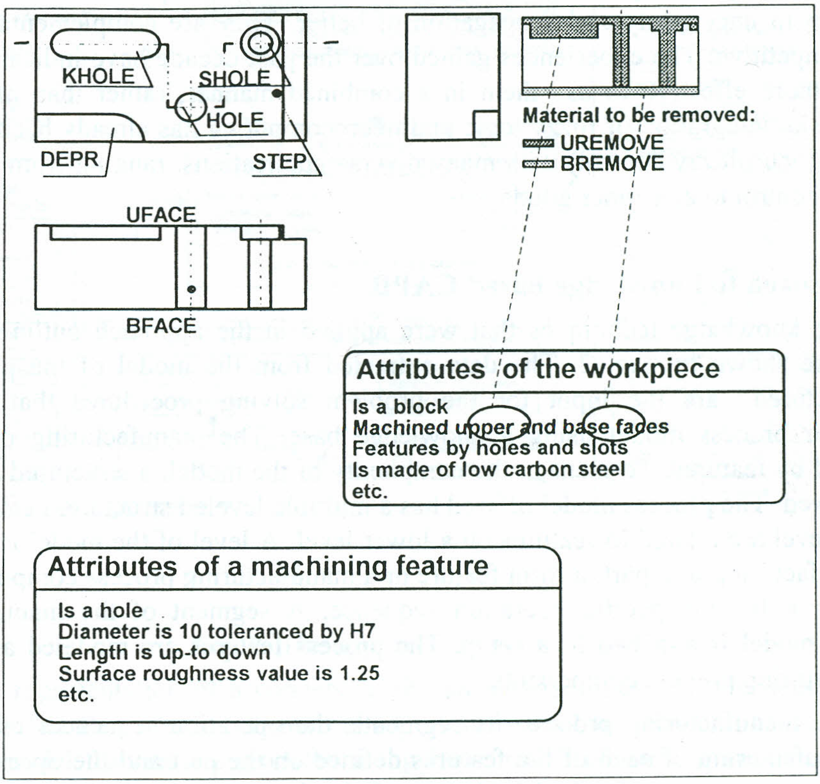

Fig. 1. Part data for process planning

Although in hard computing, imprecision and uncertainty are undesirable properties, in soft computing the tolerance for imprecision and uncertainty is exploited to achieve an acceptable solution at a low cost, tractability, high Machine Intelligence Quotient (MIQ). Prof. Zadeh argues that soft computing, rather than hard computing, should perhaps be viewed as the foundation of artificial intelligence. A center established and directed by him at the University of California, Berkeley; Berkeley Initiative for Soft Computing (BISC) devotes its activities to this concept.

The principal constituents of soft computing are

- fuzzy logic (FL)
- neural networks (NN) and

- probabilistic reasoning (PR, including genetic algorithms, chaos theory and parts of learning theory.

Fuzzy logic is mainly concerned with imprecision and approximate reasoning, neurocomputing mainly with learning and curve fitting and probabilistic reasoning mainly with uncertainty and propagation of belief. They are complementary rather than competitive. The experiences gained over the past decade have indicated that it can be more effective to use them in a combined manner, rather than alone. For example an integration of fuzzy logic and neurocomputing has already become quite popular (neurofuzzy control) with many diverse applications, ranging from chemical process control to consumer goods.

4. Approach to knowledge based CAPP

The knowledge techniques that were applied in the approach outlined in this paper are shown by Fig. 2. The data extracted from the model of the part to be manufactured are the input for the problem solving procedures that generate nonlinear process model using a knowledge base. The manufacturing process is modeled by features. To manage the complexity of the model, a structured approach is followed. The process model offered has a multiple leveled structure. Features on a higher level are related to features on a lower level. A level of the model is attached to manufacturing of a part, a form feature or a manufacturing process component as a setup or a feature-specific operation sequence. A segment of the manufacturing process model is attached to a setup. The process features are modeled as generic manufacturing process components.

The manufacturing process, its segments, the operation sequences established for manufacturing of each of the features defined on the part and the operations are handled as concepts and stored in the knowledge base. Special data structures serve this storage function .Concepts may be learned from examples or can be defied by experts. The learning procedures are supported by background knowledge. A previous work of the authors has focused on acquisition and representation of manufacturing process planning knowledge [5]. The expertise for selection of the concepts is stored in the form of classification trees. Classification trees are developed simultaneously with the definition of the concepts. Part and feature manufacturing processes are selected for clusters of parts and features accordingly. The clusters are defined by value ranges of the appropriate attributes. Facts describe capabilities of the available manufacturing processes. Real world data of equipment and tooling at a company environment are involved.

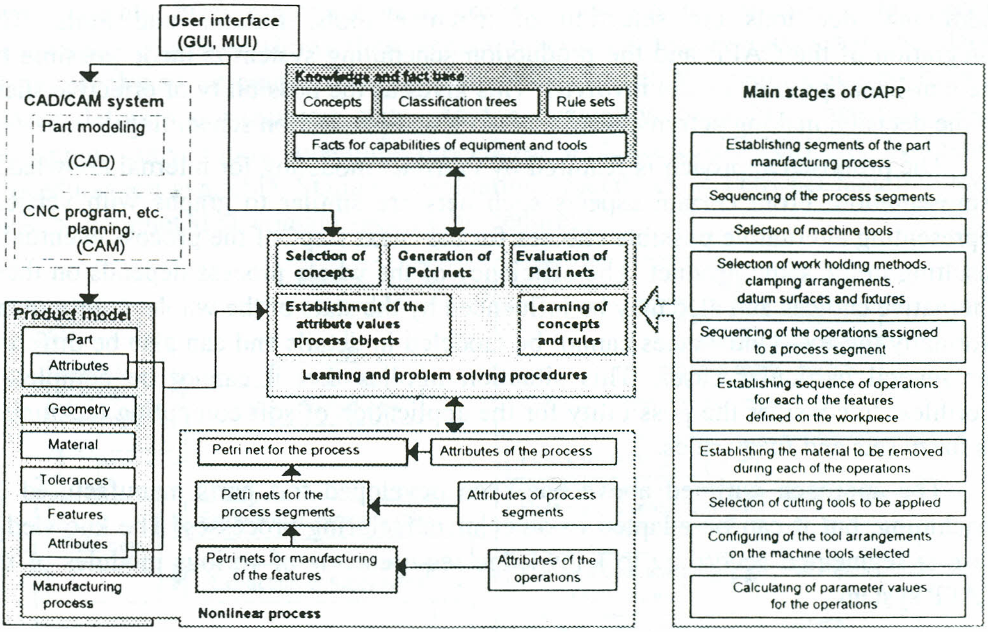

Fig. 2. The approach to process planning

The representation of a concept in the knowledge base serves generation of a Petri net. The Petri net is the internal representation of the concept. Consequently, process model features are modeled using Petri nets. Rule sets serve generation of rule elements of the Petri nets as well as checking of the concepts selected. The concept has a well-established structure while the rules can be defined and modified by experts. There are procedures for giving values to the attributes of the objects. The planning of the manufacturing process results in nonlinear process plan that contains Petri nets in their evaluated state. Process plan variants can be extracted from the nonlinear process model representation on the basis of given initial conditions. More evaluations of the Petri nets can be done by other systems. A good example of this is the production scheduling.

The decision at CAPP involve determination of the basic concept manufacturing process as well as manufacturing sub-process concepts for the form features defined on the product in a part modeling system using the Form Feature Information Model

(FFIM) concept defined by the STEP. The product model approach is followed. Additional decisions are selection of machine tools, fixtures and tools. The integration of the CAPP and the production scheduling system is made possible by the non-linear process model involved. This gives us the possibility of effective share of the decision making activity between CAPP and production scheduling.

The proposed approach is featured by Petri net modeling for internal knowledge representation. From certain aspects such nets are similar to graphs with vertices representing alternative possible choices for the "next step" of the process eventually resulting in the same product. The efficiency of the whole process depends on these alternative choices and also may be influenced by the state of the whole environment. Normally these circumstances cannot be modeled in details and can also be different for several particular cases. This situation implies that it cannot be completely worthless to consider the possibility for the application of soft computing techniques as fuzzy sets and fuzzy rules.

The approach outlined above has been developed fort parts manufactured by machining, but it can be adapted to other manufacturing processes. The knowledge base is segmented according to knowledge requirements of various modules of the CAPP system.

5. Learning, inference and uncertainty-handling methodologies

The overall procedure of the problem solving is sketched in Fig. 3. Basically, the manufacturing process is represented by a multi level model. At each level of this model manufacturing process objects are represented by generic Petri nets. For that reason three types of generic Petri nets have been defined for the part manufacturing process, the process segment and the feature manufacturing subprocess objects. These nets contain process segment or operation objects as transitions (Fig. 4.). The representations of a concept in the knowledge base contain data for places and transitions of a Petri net. Rule elements of the Petri net are retrieved from the rule set attached to the concept. A rule type place contains a single rule or a rule set. Additional places and transitions can be involved for representation of sequence relations [3].

Evaluation of a Petri net is done by firing transitions. Rule element makes a subsequent branch valid if attribute values of the part are as in the IF predicate of the rule. Evaluation of a Petri net is done by firing transitions. Rule element makes a subsequent branch valid if attribute values are as in the IF predicate of the rule. Whereas deleting, the unnecessary branches are only inactivated. Rules attached to a place element may contradict each other. If a decision amongst branches is featured by uncertainty, fuzzy reasoning procedure is involved. Representation of the concept in the knowledge base shows these special places. Tokens are assigned to the places at the usual way. In course of evaluation of a Petri net, the number and position of places define the execution state. At the evaluation of a Petri net rule based reasoning, conventional planning procedures and dedicated Petri net evaluation procedures are available. Standard evaluation procedures of Petri net handling tools must be completed by comain specific procedures.

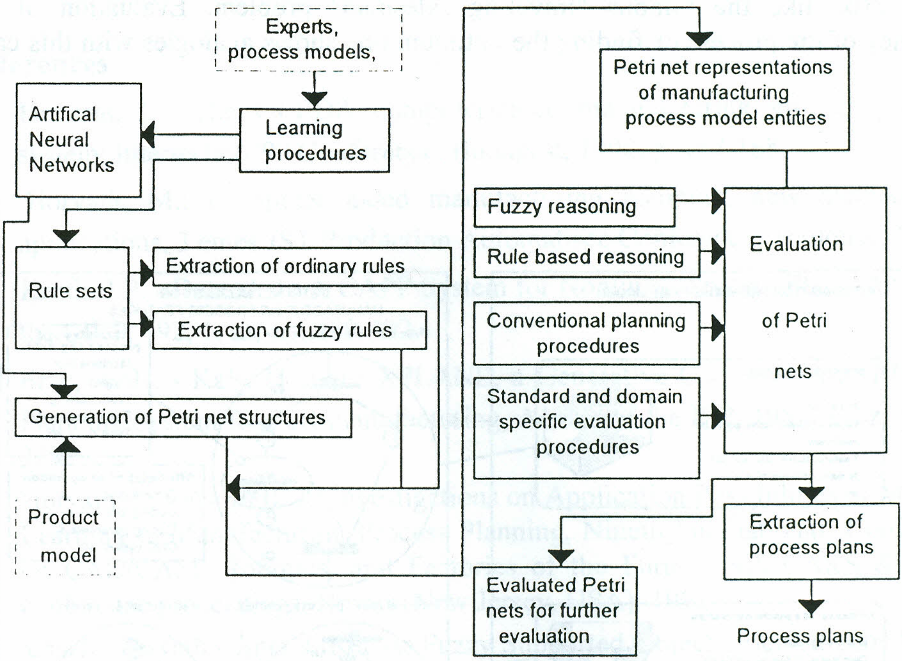

Fig. 3. The knowledge based problem solving procedure

Rules assigned to a place may contradict each other. If at a decision amongst branches featured by uncertainty, fuzzy reasoning procedure is involved. While the fuzzy inference engines require well defined and syntactically formulated rules on a "qualitative" basis, other typical tools of soft computing as ANNs also are capable of executing operation on the basis of fuzzy rules, incomplete or noisy input. Though only very slowly, besides applying them, ANNs are able to learn rules by analyzing appropriate input-output data provided by a "teacher" (supervised learning of multi-leyer feedforward networks) or establishing rules by themselves as the self-organizing Kohonen-networks operate (unsupervised learning). ANNs are also able to store the appropriate rules "encoded" in their connection weights. In contrast to the case of the fuzzy inference engine, in the case of ANNs no use of syntactically well formulated rules is necessary. Such systems can deal with unmodeled problems of high complexity for which the expert can cite a plenty of particular cases without providing us with the appropriate rules. Besides the above two basic ANN structures, their combination may also be fruitful in such applications. The third basic type of ANNs, the Hopfield network of full feedback was successfully applied in finding almost optimal solutions for problems of non-polynomial function of the dimension of the task, like the famous "traveling salesman" problem. Evaluation of the efficiency of the process or finding the optimum one shows analogies with this case, too.

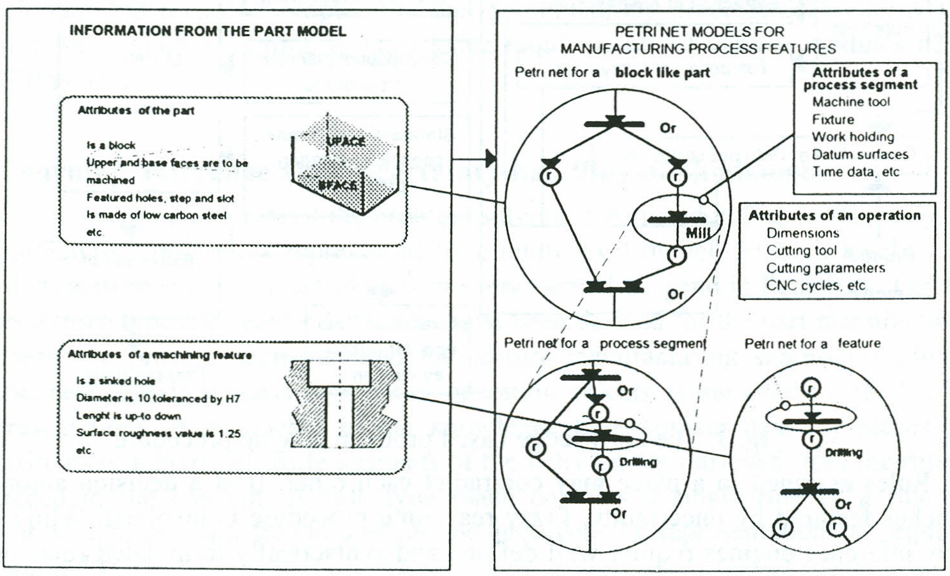

Fig. 4. Petri net modeling

6. Conclusion

In this paper, a knowledge based approach was proposed for solving problems emerged at knowledge based manufacturing process planning, ANN learning, Petri net formalism and Fuzzy based reasoning serve knowledge handling and problem solving. Integration of different knowledge engineering methods offer proper approach to development decision making tools for computer aided engineering systems. There are on-going and planned projects that use this methodology to greater or smaller extent.

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Horváth L., Rudas I.J., Török J.S., Szeghegyi A. Primjena novih paradigmi temeljenih na znanju u modeliranju računalski podržanog procesa proizvodnje

Sažetak

U radu se predlaže nov pristup temeljen na znanju, računalski podržanom planiranju procesa proizvodnje (CAPP).

Iskustva autora sugeriraju integraciju tehnika baziranih na znanju za modeliranje nelinearnih procesa. Prezentirani su problemi danas poznatih CAPP metodologija, zatim primjene tehnika računalske inteligencije, te novi pristupi CAPP problemima bazirani na znanju. Na kraju je analizirana procedura planiranja procesa, tipične etape za pojedine vrste strojnog učenja, izvođenje zaključaka i metodologija obrade u uvjetima neizvjesnosti.