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A Process Net Model Approach for Multiple Process Plans

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A process planning system that generates alternative process plans offers multiple process plans for a part, thereby providing the flexibility to cope with changes in shop floor status. In this paper, we introduce the concept of a process net as a model for the generation of alternative process plans. We also show the usefulness of the process net model in generating alternative process plans by implementing the developed system to construct process nets, and devising an algorithm to generate alternative process plans for rotational parts.

Key Words : Alternative Process Plans, Process Net

1. Introduction

Conventional process planning strategies assign just one process plan for a product, but this method lacks flexibility and cannot cope with changes in shop floor status. Therefore, a combination of a process planning system which provides alternative process plans with a scheduling system that considers current shop floor status is required (Hou and Wang, 1991 ; Park et al., 1996 ; Kang et al., 1997).

In order to provide alternative process plans, a variety of strategies have been proposed such as NLPP (Non-Linear Process Planning), CLPP (Closed Loop Process Planning), DPP (Distributed Process Planning) (Zhang and Alting, 1994). An NLPP system generates every possible process plan prior to scheduling. At the moment of scheduling, the system selects a feasible process plan among the process plans made in advance. FLEXAPLAN (Detand and Leuben, 1990) is an example of an NLPP system. NLPP systems have the problem of reducing the time to search nonlinear process plans. A CLPP system generates only one process plan per product. If the process plan becomes infeasible due to a change in shop floor status, the system modifies the process plan or generates another (Zhang and Alting, 1994). A DPP system conducts process planning and scheduling at the same time in order to generate feasible a process plan. IPPM (Integrated Process Planning Model) (Zhang, 1993) and IPPS (Integrated Process Planning Project) (Huang et al., 1992) are examples of DPP systems. CLPP and DPP systems have not been put to practical use because they require extremely high performance hardware for real time process planning and scheduling.

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In this paper, we introduce the concept of a process net which is based on a nonlinear process plan for NLPP. The process net can be put into use for the integration of process planning and scheduling without the requirement for high-performance hardware. Also, it is easy and straightforward to apply graph search algorithms to the process net ; that is, we can reduce the net search time. We also demonstrate the usefulness of process net by implementing a system for process net generation, generating a process net for a cylindrical part, and finally produce a process plan from the generated process net.

2. Process Net

In the early 1990's, Zhang and Kruth proposed a concept which is similar to the process net. Zhang constructed graphs which consist of element processes and developed a net search method to generate process plans from the graph (Zhang, 1993). He also proposed ALPS, a specialized language for graph search (Huang et al., 1992). Kruth constructed Petri-net of processes for FLEXAPLAN (Kruth and Detand, 1992).

As shown in Fig. 1, a process net is an AND-OR graph whose nodes are element processes. Multiple process plans can be extracted from the process net. In order to generate process plans from the process net, a net search should be carried out from the head node to the tail node. When two branches are connected by and-split and and-join nodes, denoted as a_s and a_j in Fig. 1, both branches must be visited. In case two branches are connected by or-split and or-join nodes, denoted as o_s and o_j in Fig. 1, only one branch is visited. Figure 2 shows process plans, in tree form, which can be extracted from the process net in Fig. 1. Those process plans can be used as input data for NLPP or NLPP-like systems.

In this paper, we define a 'feature process net' for each feature of cylindrical parts. In feature process nets, element processes for the feature are stored in net form. A 'Process net' can be constructed by superposition of feature process nets. Assigning machines for the element processes in the process net, the 'machine net' is generated. We also devised an algorithm to search the process nets and the machine nets in order to produce process plans.

As demonstrated in Fig. 1 and Fig. 2, a process

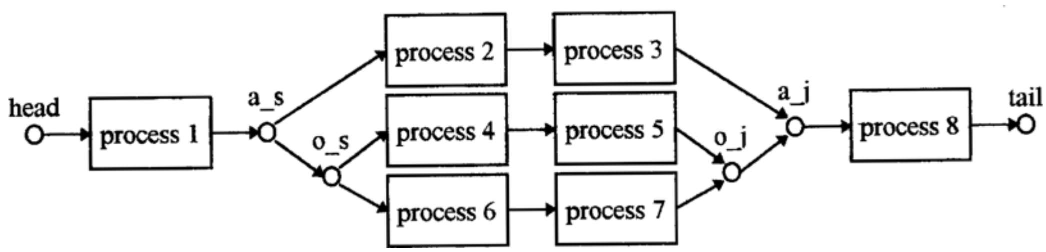

Fig. 1 An example of a process net.

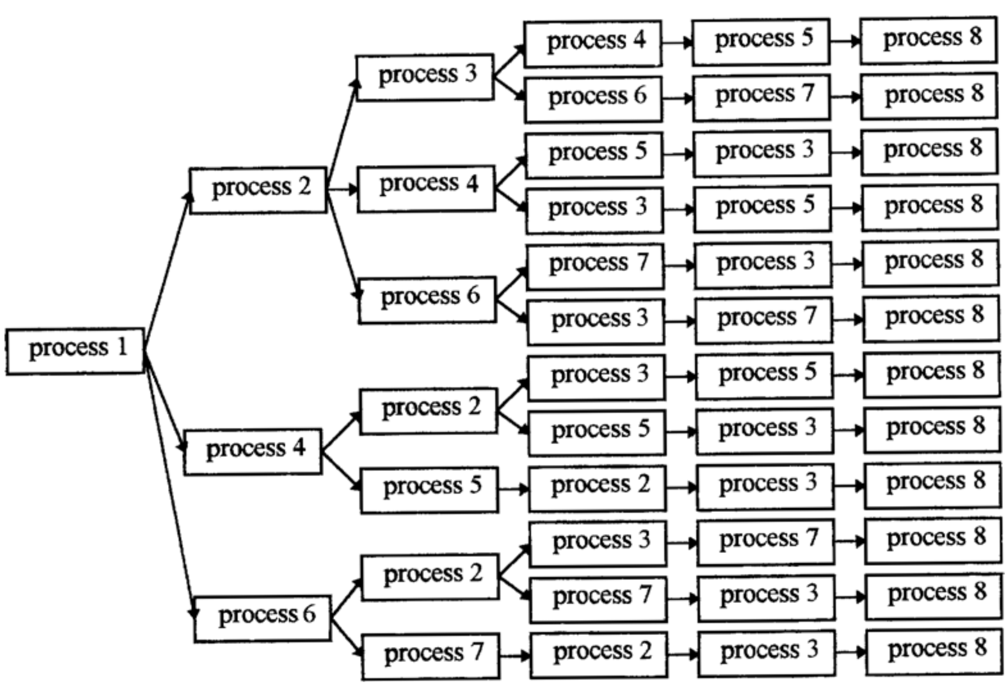

Fig. 2 Alternative process plans generated from the process net in Fig. 1.

net can store multiple process plans in condensed form. Therefore, a system utilizing process nets can save considerable memory to store process plans. Moreover, just like the case of NLPP systems, a system using process nets generates process plans prior to scheduling. Hence, this method doesn't require the performance of CLPP or DPP. With these merits, this method can be put to practical use readily.

3. System Configuration

The system is comprised of five modules : feature input module, process net generating module, machine net generating module, process plan generating module, and graphic output module. The First four modules conduct, respectively, the four steps of process planning : (1) feature input, (2) process net generation, (3) machine net generation, and (4) process plan generation. The Graphic output module is an accessory module which interprets the binary data of process nets and machine nets into net graph drawings. In addition to the five modules, the system contains a feature process net file and a machine data file. In the feature process net file, the feature process net of each feature is defined. The machine data file contains machine availability information in the form of available time segments of each machine.

3.1 Feature input

With the interactive feature input module, a user inputs the feature information of a part :

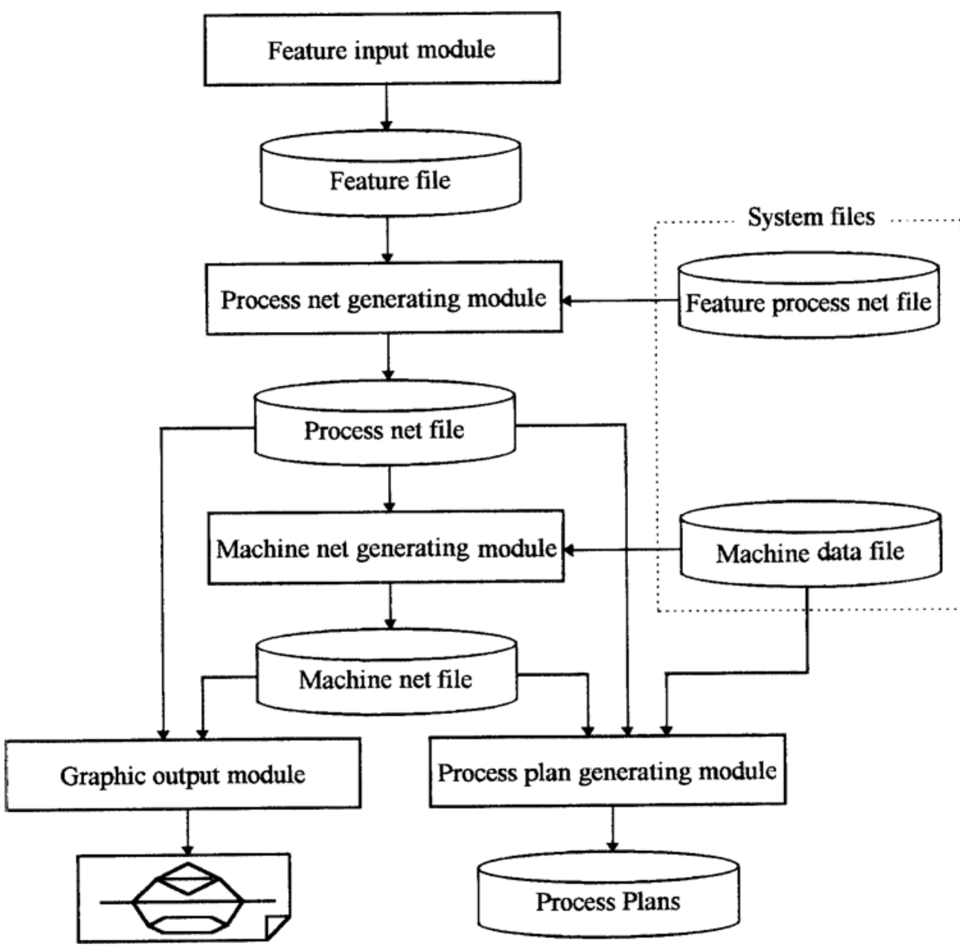

Fig. 3 Overview of the system.

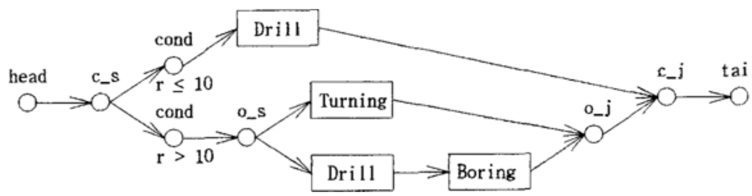

Fig. 4 Feature process net for inner diameter of cylindrical parts.

feature names (the user selects among the predefined feature names, e. g., OUTER_DIAMETER, INNER_THREAD, END_SURFACE, and so forth), dimensions, setup orientations, priorities, and machining times. Input data are stored as a feature file.

3.2 Process net generation

The feature process file stores the processes of each feature in net form as shown in Fig. 4. Nodes of the net are classified in to 10 types : HEAD, TAIL, PROCESS, AND_SPLIT, AND_JOIN, OR_SPLIT, OR_JOIN, CONDITIONAL_SPLIT, CONDITIONAL_JOIN, CONDITION.

HEAD : Start node of a feature process net.

TAIL : Terminal node of a feature process net.

PROCESS : This type of node represents a process. In Fig. 4, the PROCESS nodes are expressed as rectangles.

AND_SPLIT/AND_JOIN : These are used in pairs. It connects more than one group of processes, any group of which can be processed first, and every group of which should be processed.

OR_SPLIT/OR_JOIN : These are used in pairs. It connects more than one group of processes, only one group of which should be processed.

CONDITIONAL_SPLIT/CONDITIONAL_JOIN : These are used in pairs. It connects more than one group of processes, only one group of which should be processed according to the conditions.

CONDITION : The First nodes of the node group connected with CONDITIONAL_SPLIT and CONDI-TIONAL_JOIN. They indicate conditions pertaining to dimension, precision, etc.

Figure 4 is a trial feature process net for the inner diameter of a cylindrical part. If the radius of the feature does not exceed 10, the feature should be processed by drilling ; otherwise it can be processed either by turning or drilling and boring.

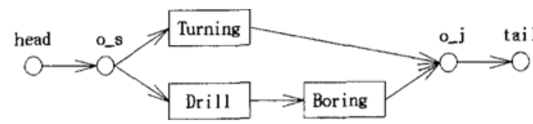

Fig. 5 Feature process net for inner diameter of cylindrical parts in case of r > 10.

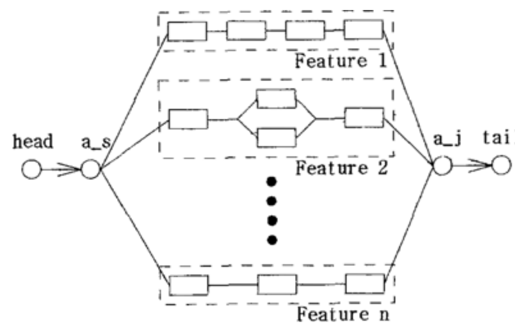

Fig. 6 Generation of process net by combination of feature process nets.

The process net generating module retrieves the feature process net from the feature process net file, then searches the net and deletes all nodes except those that coincide with the conditions from the feature file. For instance, in the case of radius > 10, the feature process net of Fig. 4 turns into the net of Fig. 5.

When a feature process net is generated for every feature, all the feature process nets are combined by AND_SPLIT and AND_JOIN as shown in Fig. 6 to construct the process net of a part.

3.3 Machine net generation

The Machine net is constructed from the process net file and the machine data file which provides the available time segments of each machine. The machine net generating module assigns an available machine to each PROCESS node of process net. The output of this step is stored as a machine net file.

3.4 Process plan generation

Process plans are generated from the process net file, the machine net file, and the machine data file. This step is conducted at the moment of scheduling, considering the machine availability information provided by the machine data file.

First, pmatrix (precedence matrix) $[P]$ is constructed as the following rule : in case the i-th feature should be processed after the j-th feature, $P_{ij}=1$, otherwise $P_{ij}=0$. The pmatrix should be constructed interactively. Thus, this process must be carried out by an experienced engineer. When pmatrix is prepared, the process plan generating module conducts a net search to obtain the process plans.

In general, numerous process plans are extracted from one process net. Therefore, a net search algorithm is required to extract a reasonable number of best process plans in reasonable time. The devised algorithm is a variant of a depth-first -search algorithm for AND-OR graphs with a heuristic of minimizing the total processing time. When a user selects N, the total number of process plans to generate, the process plan generating module generates N process plans which have the smallest total processing times.

4. Demonstrative Example

To evaluate the implemented system, process planning was conducted for a simple cylindrical part. This test part has five features as indicated in Fig. 7. The pmatrix of this part is :

$$[P]=\begin{bmatrix} 0&0&0&0&0\\ 0&0&0&0&0\\ 0&0&0&0&0\\ 1&1&0&0&0\\ 1&1&0&1&0 \end{bmatrix}$$

The process net of the part in Fig. 7 is shown in Fig. 8. Figure 9 shows the machine net of the corresponding process net in Fig. 8. The total number of process plans to generate, N, was set to 5. The 5 process plans which have the smallest

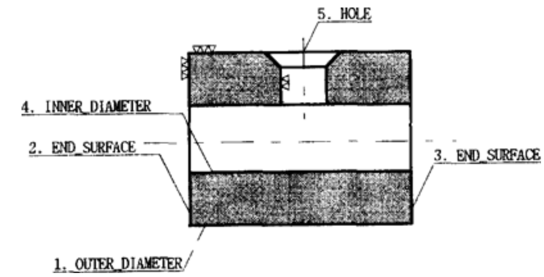

Fig. 7 An example of a cylindrical part.

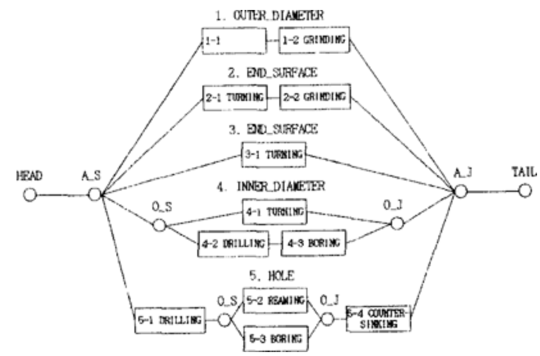

Fig. 8 Part process net.

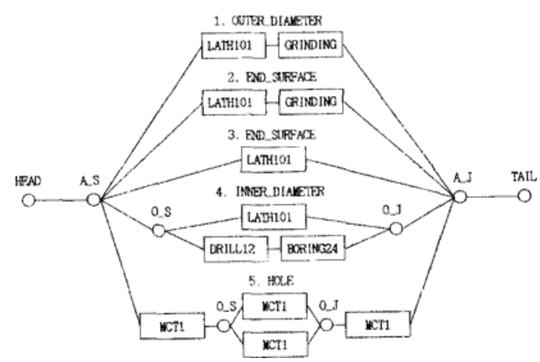

Fig. 9 Part machine/tool net.

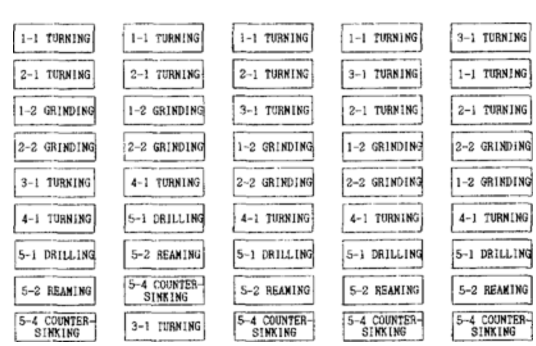

Fig. 10 Generated process plans.

total processing times were generated and are listed in Fig. 10.

5. Conclusion

In this paper, a process planning system providing alternative process plans with the concept of a process net was implemented. Taking advantage of the process net, this approach requires less net search time than NLPP and less hardware performance than CLPP and DPP. Also, a net search algorithm to extract best process plans in a reasonable time was developed.

Further research is required to modify the process net to deal with prismatic parts. The structure of the process net needs improvement as well, to include plastic processing, heat treatment, and other possible non-conventional processes.

As the process net grows large, it takes enormous time for net search. Thus the net search algorithm introduced in this paper has limitations and an alternative approach for net search should be considered. Genetic algorithms and simulated annealing may carry out the net search efficiently. This research will be conducted in future work, which will adopt genetic algorithms for the search of the process net.

Acknowledgements

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