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A Web-based process planning optimization system for distributed design

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Abstract

In this paper, a process planning module, which can optimize the selection of machining resources, determination of set-up plans and sequencing of machining operations to achieve optimized process plans, has been wrapped as services and deployed in the Internet to support distributed design and manufacturing analysis. The module includes four intelligent approaches, and a Tabu search-based approach is explained in this paper to illustrate the optimization process. A Web-based prototype system has been setup for users to carry out visualization-based manipulations and process planning of design models by invoking the services remotely. The Web-based system has been integrated with a distributed feature-based design system, and the latter can generate design models and re-represent them in an XML representation based on VRML and attributes of features to provide the input of the former. Through effective utilization of the Web and Java technologies, this system is independent of the operating system, scalable and service-oriented, and can be used by a geographically distributed design team to organize concurrent engineering design activities effectively.

Keywords: Process planning; Web-based system; Distributed design

1. Introduction

As one of the most popular Internet tools, the Web aims to provide a light-weight and an operating system-independent platform for users to search, browse, retrieve and manipulate information disseminated and shared remotely. Based on the Web, design models can be dynamically shared and updated in an Internet environment and conveniently accessed and manipulated by remotely located people from the design team, management, marketing, maintenance and customers for efficient design collaboration, design process monitoring, product pre-review and evaluation.

Realizing the merits of the Web technology, researchers and developers have been actively exploring and developing Web-based design and manufacturing systems. Chen and Liang [1] proposed a Web-based system to integrate and share engineering information to support design and manufacturing activities such as domain investigation, functional requirement analysis, and system design and modelling. Functional modules in their system are wrapped and supported by CORBA for communication. The CyberCut system developed at the University of California at Berkeley [2] is a Web-based system integrating product design and process planning as a Java Applet program. The FIPER (Federated Intelligent Product EnviRonment) system [FIPER Project (www.fiperproject.com/fiperindex.htm)] [3,4] funded by NIST is to develop a new product design and analysis technology. The main objective of this system is to develop a Web-based distributed framework for design analysis and product lifecycle support based on component mechanisms and configurable workflow mechanisms. It can provide open and flexible capabilities to incorporate existing analysis and design tools/methods through Java-based wrapping mechanisms including Java Native Interface (JNI) and the FIPER SDK toolkit. Xiao et al. [5] developed the Web-DPR system as an

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infrastructure to support collaborative design and manufacturing. Based on the Java Remote Method Invocation (RMI) mechanism, agents and an event-based mechanism, the functional modules of the systems can be linked and coordinated effectively. Shyamsundar and Gadh [6] developed a new geometric representation named as AREP and a collaborative prototyping system based on this representation to perform real-time geometric modification for components/sub-assemblies in an assembly model. In the work of Choi et al. [7], Web service architectures were utilized to establish a new generation of distributed design and manufacturing platform based on XML schemas and a communication protocol SOAP (Simple Object Access Protocol) to provide a neutral data exchange format and effective capabilities in interoperability, integration and Internet accessibility of services. From these works, some common characteristics can be observed and an important trend is that application programs in product design, process planning, engineering analysis and simulation are embedded in a Web environment as Application Service Providers (ASPs) for remote invoking and manipulation to support distributed product design and development. This manner can bring many advantages such as avoiding complicated installations for individual computers, easily upgrading application modules and lowering the acquisition costs for Small and Middle Enterprise (SMEs) through renting services.

In this paper, a Web-based system has been developed to support the establishment of a distributed design and manufacturing environment. The system can serve as a platform for distributed users to carry out process planning activities through optimizing the selection of machining resources, determination of set-up plans and sequencing of machining operations of a design model. Four intelligent approaches have been developed to solve this optimization problem, and a Tabu Search (TS)-based approach will be described to explain the process. The optimization module has been deployed in the Internet as Java Servlet-based application services based on a multiple-layer wrapping mechanism. Java Applet, Java2D and 3D technologies have been utilized in the system to develop a visualization-based manipulation environment of the design models and the optimization results. Through an XML-based data exchange format based on features and VRML, this system can exchange information with a distributed feature-based design system to form an integrated design and manufacturing analysis environment across the Internet.

2. Methodology for process planning optimization

As the crucial activities in a process planning system, selecting suitable set-up plans, determining machining resources such as machines and cutters, and optimizing the sequence of the machining operations are relatively important to ensure satisfactory solutions with lowest machining costs. Considering that decision processes for these aspects are sometimes contradicting, and the evaluation criteria with different consideration perspectives can also be conflicting in some cases, some developed reasoning methods such as knowledge-based reasoning [8–10], graph manipulation [11,12], Petri-nets based approach [13] and fuzzy logic reasoning [14,15] cannot effectively solve this problem with a global optimized result. Recently, evolutional and heuristic algorithms have been applied to the process planning research, and multiple objectives, such as the minimum use of expensive machines and tools, minimum number of set-ups and tool changes, and achieving good manufacturing practice, have been incorporated and considered as a unified model to achieve a global optimal target [16,17]. Four approaches, including Genetic Algorithm (GA), Simulated Annealing (SA), hybrid GA-SA and TS, have been applied to solve this problem. The optimization objective is to reduce the total machining cost. Some details for an improved TS-based approach, which can generate process plans with near-optimal or optimal results according to the optimization objective, will be disclosed as follows.

2.1. Representation of the process planning problem

A part consists of a series of features, and each feature can be mapped to a set of machining operations which form the elements of a process plan. A process plan usually needs to determine the sequence of the operations, set-ups, and the machine and cutter for each operation. The objective is to generate the most economical plan evaluated from the numbers of required set-ups and the utilization of machining resources. In each operation, there is a set of alternative machines, cutting tools and set-ups (here simplified and represented as Tool Approach Directions (TADs)) under which the operations can be executed. The proposed TS approach determines an optimized sequence of the operations and the utilized machine, cutting tool and TAD chosen from their corresponding candidates according to certain optimization criteria, which include the costs for the utilized machines (TMC), utilized tools (TTC), Set-ups (TSC), machine changes (TMCC) and tool changes (TTCC). For violated constraints, a penalty cost (PC) is computed. The detailed formulas and computation processes for these criteria can be found in [17]. The geometric and manufacturing interactions between features as well as the technological requirements in a part can generate some preliminary precedence constraints between the machining operations. These interactions and technological requirements can be summarized into several types: (1) fixture interactions, (2) tool interactions, (3) datum interaction, (4) thin-wall interactions, (5) feature priorities, (6) material-removal interactions, and (7) fixed order of machining operations. The definitions and examples of these constraints are given in [17].