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e-CAPP: A distributed collaborative system for internet-based process planning

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ABSTRACT

Advances in distributed technologies have enabled engineers to communicate more effectively, collaborate, obtain, and exchange a wide range of design resources during product development. Shared internet-based virtual environments allow experts in remote locations to analyze a virtual prototype, together and simultaneously in centers in which the product is being developed.

This paper presents a system for distributed and collaborative environment which could assist manufacturing enterprises and experts in discussing, suggesting, evaluating and selecting best process plans for family of manufacturing parts. The represented e-CAPP system enables the implementation of expert knowledge in an appropriate knowledge repository. The knowledge from this repository is integrated into intra-company CAPP systems and used while generating process plans for new products. The proposed internet-based collaborative environment, dedicated to distributed process planning, is yet another step in the direction advancing of distributed manufacturing.

1. Introduction

Rapid development of internet technologies allows rapid growth of distributed application systems that exceed traditional physical and timing constraints, and helps connecting geographically dislocated users, systems, resources and services. Efficient utilization of latest information and communication technologies, as well as technologies in the field of company's business, is only possible in flexible and collaborative working environment [1]. This environment enables successful cooperation among project teams based on the exchange of digital information, thus ensuring greater innovation and better quality, with the reduction in cost and time required to launch a new product to the market [2]. Frequent product changes result in the emergence of multiple product variants, while distributed collaborative engineering brings new tools and methods for more efficient administration work during all stages of product's lifecycle, its different variants and customer needs [3]. By relying on web-based collaborative systems, designers and engineers are able to exchange knowledge and share work at the global level [4–6]. In modern conditions, the production of complex products is realized on principles of distributed manufacturing in a number of enterprises. These enterprises are specialized for partial process plans. Complex products, which consist of a large number of parts, components and modules, are assembled into a functional product in one enterprise, but these are often manufactured in different parts of the world. Therefore, it is crucial to have an adequate coordination between teams who work in different places on the same project [7,8].

Process planning represents one of the most important tasks to be solved in the distributed manufacturing environment, in which different companies participate in collaborative product development [9]. Activities related to process planning at the intra-company level are usually realized by applying the CAPP systems [10–12]. Thereby, it enables the application and implementation of procedures that use engineering drawings, bills of materials and other technological specifications as input information in order to identify and select machining processes, resources, process operations and other parameters necessary to transform raw material into a finished product [13]. CAPP tools integrate decision-making mechanisms and knowledge bases and thus build the basis for defining the machining processes. However, their integration with other functions in the enterprise, such as financial flows, production planning, manufacturing resource planning and control, quality control, procurement etc., is not simple by any means [14]. Significant changes to enterprise strategy and manufacturing paradigms have led to the development of Internet/Web-based pro-

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cess planning and manufacturing in order to support a networked manufacturing environment [15]. Integration and networking are necessary in enterprises that participate in the collaborative process with other enterprises in order to accelerate the development of new products, where competitiveness at the global market represents the main motive. The network of enterprises that participate in the collaboration that includes suppliers and end-users can be defined as the extended enterprise [16–19]. The purpose of this integration is to achieve competitive advantage by maintaining the distributed cooperation along the entire organizational structure. Function of the extended enterprise is based on the use of the Internet because this way, it provides the infrastructure through which the information is simultaneously available to all participants in the production planning, whether they are designers, process planners, production managers or production workers. Therefore, new paradigms that combine internet technologies and manufacturing are introduced in the planning process. Some of them are Cloud manufacturing (CMfg) [20–23] and Internet of Things (IoT) [24,25]. However, from the viewpoint of process planning, integration is often slowed down by different constraints. Those are mostly constraints within the integration of CAD/CAPP/CAM systems [26], as well as constraints on how to share information about manufacturing capacities and resources, which are necessary for dislocated experts for process planning [27].

These problems can be solved by means of distributed, flexible open systems for process planning in the collaborative environment. A system for collaborative process planning should help users to define process plans with the required level of detail. These levels are known as meta, macro and micro process planning. Meta or conceptual process planning is performed in order to determine production processes and machines appropriate for achieving shape, size, quality and cost of parts that are planned. Macro process planning is responsible for the specification of equipment, minimum number of process operations required for manufacturing a part, as well as the operation sequence. Micro process planning refers to the selection of tools, fixtures, generation of CNC programs and definition of other parameters related to the production process so that productivity, product quality and manufacturing costs remain optimal [27,28].

A common scenario for the extended enterprise is the case in which there is one enterprise that uses manufacturing services of other, geographically dislocated enterprises, in order to produce the necessary product quantity and satisfy the appropriate quality standards, cost and delivery time [19]. Usually, the observed enterprise requires process planning in the collaborative way, with consideration of knowledge and experience of people involved in the manufacturing process. To achieve an efficient process planning, it is required to identify relevant collaborative activities, information and knowledge flows, and integrate them into a collaborative working environment which can provide good communication and coordination.

2. Review of distributed and collaborative process planning systems

Previous studies in the field of collaborative and distributed process planning have led to the emergence of a number of prototype models that differ in terms of functionality, way of communication, applied software tools and data structures. Here, some of the most famous solutions developed in this field are briefly reviewed.

COMPASS is a system for materials, processes and apparatus selection that helps designers to define potential problems in manufacturing in the early stages of product development, and also enables efficient planning of heterogeneous process plans in manufacturing [28]. CoCAPP is a system for process planning that uses mechanisms of cooperation and coordination which are embedded into distributed agents [29]. CyberCut is an Internet-based CAD/CAM system that enables the generation of 3D prismatic parts by simulating processing operations on raw workpieces until it transforms them into the final part [30]. IMPlaner system represents a prototype model for distributed definition of manufacturing activities [31]. The system relies on the existing CAD/CAM systems and specialized CAPP solutions. MASCAPP is an object-oriented system for process planning [32]. The prototype of this system is focused on prismatic parts and uses techniques of artificial intelligence, multi-agent systems and STEP-NC standards. VCAPP is a networked virtual production system for small and medium-sized enterprises [33]. In this system, dislocated users share CAD models in the virtual realistic environment and develop process plans. The system for collaborative process planning and manufacturing within the product lifecycle management is developed in [34]. Here, the technological infrastructure that includes UML for representing functional collaborations, as well as for CAPP and CAM systems, is defined and implemented. Authors in [17,18] showed basic functional requirements and technological infrastructure required for the development of collaborative environment for process planning (CPP) and its implementation in the PLM system. An integrated system for product development named INFELT STEP is comprised of CAD, process planning and CNC code generation based on an integrated data structure. This system is a three-layered integrated and interoperable platform for collaborative and interoperable product design and development which is based on the STEP standard [35,36]. Adaptive process planning (APP) approach for machining is a new methodology studied in [37,38]. This mechanism includes a two-tier system architecture, generic supervisory planning, machine-specific operation planning, and adaptive setup planning. The framework in [21] is developed on the Cloud platform and consists of two main services that are responsible for monitoring of machine availability and deriving process plans. This is a novel framework for process planning that utilizes machine availability monitoring data obtained in real-time with the purpose of identifying feasible and adaptive process plans.

Based on the analysis of the above reviewed systems, the original model of e-CAPP environment is developed. By implementing internet technologies, this model links distributed process planning knowledge sources. It is a distributed collaborative CAPP system which, while generating process plans, uses opinions and experience of geographically dislocated experts, or so called heuristic knowledge of an online expert virtual team. Hence, the system, with the aid of internet technologies, enables the online implementation of expert heuristic knowledge in the knowledge base of an intra-company CAPP system. Heuristic expert knowledge, based on the personal experience and beliefs, through the knowledge repository, dynamically changes and supplements the knowledge used for generating process plans. Knowledge base of intra-company CAPP systems changes according to the opinion of an expert virtual team that becomes the primary opinion when generating a standard process plan for part family. Such an approach differs from the previous distributed collaborative process planning solutions.

The system also uses a multi-criteria decision approach for evaluating process plans which is insufficiently represented in the previous distributed process planning systems, except in one paper which used a hybrid methodology for determining the actual status of machine tools [21].

Numerous studies in this field put more emphasis on the micro process planning [30,33,35]. The meta and macro level of process planning are of greater significance in the e-CAPP system where the opinions of experts are essential and crucial. Apart from machining operations, the analysis of process plans also covers the analysis of selected raw material, casting operations, heat treating operations, as well as auxiliary operations. This is very important because poor