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Knowledge discovery approach for automated process planning

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Abstract

Manufacturing companies in industrialized countries are facing the challenge of achieving shorter times-to-market for their products while also coping with higher and more frequent initial planning efforts for customer specific products. Automated process planning is suited to dissolve this conflict by reducing manual planning efforts and enhancing planning productivity. However, existing computer-aided process planning (CAPP) approaches primarily shift planning efforts towards establishing and updating deterministic rules for planning algorithms manually. This paper shows the potential of using feedback data from Industrie 4.0 production systems as well as design features in a statistical approach to automatically determine initial process sheet information for new products. Feedback data from the manufacturing system is used as a digital representation of the production process. Interdependencies of component characteristics and production processes can be statistically identified via a knowledge discovery in databases (KDD) approach. These interdependencies in turn can be used to automatically deduce rules for CAPP planning algorithms. The presented integrated approach also includes further increasing the level of accuracy and comprehensiveness of the initial process sheet information, as well as updating the planning rules and assumptions following a control loop model. Necessary input and output parameters of the approach are being described, as well as the approach itself, including several steps to systematically incorporate the implications of component characteristic interdependencies on the necessary process steps. Finally, the approach and its potentials are illustrated using a set of real data from a manufacturing company.

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1. Introduction

Ensuring a competitive time-to-market for product development and time-to-customer for order fulfillment respectively are important requirements for manufacturing companies [1]. These challenges are especially valid for individual and small batch production [2]. Decreasing product lifecycles [3] as well as the development towards customer individual product variants [4,5] lead to an increase in planning efforts per unit produced and the necessity to rationalize planning activities [3].

In addition to planning efficiency, the use of process sheets as a crucial document for production control activities, poses quality requirements on the planning process that are often not met in reality. The use of incorrect enterprise resource planning (ERP) master data and disregard of product and/or process changes can lead to the use of incorrect process sheets [6,7]. Implicit planning knowledge of domain experts furthermore can lead to non-standardized, inconsistent planning processes and results [8].

To address the illustrated challenges regarding planning efficiency and quality, the automation of process planning tasks by using computer-aided process planning (CAPP) has been researched [1] and commercial software is in widespread use. Externalizing planning knowledge to manually set up and configure CAPP systems to be used productively however, is time consuming and intricate [1,9]. In order to further improve process planning efficiency, it is necessary to automate the externalization of process planning knowledge. Therefore, this paper proposes an approach to automatically elicit process planning knowledge by statistically analyzing inter-dependencies of component characteristics and production

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processes. These interdependencies in turn can be used to automatically deduce rules for CAPP planning algorithms. To ensure an up-to-date knowledge base at all times, feedback data from recent production orders is used as a representation of the production processes.

The paper is structured as follows: Section 2 discusses process planning, feature technology, as well as CAPP approaches and existing approaches for automated discovery of planning knowledge. Section 3 subsequently presents the approach for automated process planning. The presented approach is then illustrated using a set of feedback data from an individual and small series manufacturer in section 4. This paper concludes with a summary of its findings and an outlook upon further research in section 5.

2. State of the art

This section describes the fundamentals of process planning as the basis for production scheduling and control activities. Publications discussing CAPP approaches as well as approaches to automatically identify and elicit process planning knowledge from existing databases are being reviewed and a research gap is identified.

2.1. Process planning

In the product creation process, process planning constitutes the activity that links product design and manufacturing. Process scheduling as a subsequent activity is then responsible to take appropriate action in order to ensure the operations are being carried out as planned. As a short term planning activity, process planning determines feasible and economically viable manufacturing sequences considering the available resources. Macro level process planning, as used for production scheduling and control activities, incorporates the four planning problems blank selection, process sequence determination, resource allocation and standard time determination. Planning results are then documented as process sheets (also process plans) and constitute the pivotal document for the manufacturing activities [1,3].

Traditionally, manufacturing experts, based on expertise and experience [8], carry out process planning manually. Information asymmetry among planning experts, insufficient feedback from manufacturing, unchecked reuse of process sheets, as well as the complexity of the planning problem itself, often lead to insufficient planning results. Considering these circumstances, CAPP systems are increasingly in widespread use in order to improve planning quality and efficiency [10]. However, compared to other computer-aided technologies like computer-aided design (CAD), CAPP systems have lower market penetration [10,11]. Considerable implementation efforts due to system architecture and the integration of implicit planning knowledge, specific to the implementing company [1,3] can be reasons for this circumstance.

2.2. Feature-technology

In order to apply CAPP technology, it is necessary to specify the component and its characteristics geometrically in a way that can be easily interpreted by CAD, as well as CAPP systems [10]. For this purpose, component information is usually represented by features. Features contain the geometric description of the component elements, as well as their spatial relations. The use of feature-technology and feature-based CAPP systems is widely accepted in scientific publications and used in commercial software [1,10]. Approaches for feature-based design of components are distinguished from approaches for retroactive feature-identification from CAD-models [12]. A mostly consistent use of feature-descriptions among systems and platforms is achieved by employing the feature-descriptions standardized in STEP-files (Standard for the Exchange of Product Model Data) [10,13].

2.3. Automation approaches to process planning

Numerous approaches to automate aspects of the planning process have been researched and published for decades (cf. [8,14]). Generative planning approaches, which enable the automated process planning for new components, have been at the center of this research, but are also the most difficult to implement [10]. Approaches frequently used to link company-specific product and process information in the automated planning process are decision trees and tables, the use of fuzzy rules and of artificial neural networks (ANN).

Decision trees and table-based approaches have been used to solve various kinds of planning problems. Using defined if-then relations, process information can be linked to the component based on its features and their parameter values [1]. Sadaiah et al. propose the use of a decision table-based approach for the planning of prismatic components [15]. The focus of the approach is an economically sensible and technologically feasible grouping of features and therefore assigned processes into machining set-ups. Lee at al. also pursue the goal of grouping necessary processes into an economically advantageous sequence of machining set-ups [16]. The emphasis in this approach is put on integrating associated features into “composite features”, as well as determining the standard times and prioritization of the processes. Other exemplary decision table-based approaches also focus on the micro planning level and assign processing operations within machining set-ups [17,18]. Raman et al. allocate machine tools to component features based on their ability to manufacture the required geometries and shapes [12]. An approach for macro level process planning is proposed by Nonaka et al. [11]. Machining volume is decomposed into basic shapes, which in turn are assigned to suitable resources, with the objective to generate alternative routings in order to facilitate a uniform utilization of capacities.

Fuzzy logic-based approaches allow for a generalization of unambiguous decision rules used in decision trees and tables. Value ranges of input parameters can be attributed to several classes of output variables at the same time when using fuzzy logic [19]. Fuzzy logic can be used to determine the suitability of existing process plans for a new production order and for machine tool and resource selection as well as for choose machining parameters as a function of material properties as well as feature size [20].