Ontology-Based Finding of Feasible Machine Changes

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Abstract. In the event of a machine fault, feasible machine changes have to be reviewed by the operation scheduling and dispatching to avoid remarkable delays. In this approach, this is achieved by an automated identification of alternative machine tools and a reliable validation. First, a capable machine that satisfies the requirements of the NC program is searched within an ontology. Therefore, the ontology contains a description of all relevant characteristics of specific machine tools and expert rules to derive provided capabilities. Second, the NC program is validated on a virtual machine tool to ensure its accuracy.

Keywords: Computer-aided process planning (CAPP); Computer-aided manufacturing (CAM); Knowledge based system; Ontology

1 Introduction

The increasing amount of individualized products requires a highly flexible production system. In the field of metal machining, the needed flexibility is achieved by numerical-controlled (NC) machine tools. The wide spectrum of work pieces leads to the use of heterogeneous machine tools with different capabilities. However, most work pieces can be manufactured by different machines. In this case, the selection of the most economic machine tool at start of production for each manufacturing step is essential to realize competitive prices in high-wage countries.

2 Problem analysis

2.1 Today's lack of resource flexibility for machining processes

Machine tool selection. The appropriate selection of a machine tool for each manufacturing step is based on the expertise of qualified and experienced employees. This decision is taken days or weeks before start of production on the shop floor. The shop floor is a complex and an ever-changing environment. Hence, the selected machine might not be the most economical machine tool for the actual available resources [1]. Investigations have shown that 20 – 30% of the initial process plans have to be altered before the start of production [2]. Common reasons for that are unpredictable conflicts and changes in the economic planning, organization and available capacities [3].

adfa, p. 1, 2011.

Binding on selected machine due to G&M code. After a machine is selected, the computer-aided manufacturing takes place (CAM); this is the transformation of the work piece geometry into low level part programming as a sequence of machining operations (G&M code) referred to as NC program. The transformation depends on the machine's characteristics like the control type, axes and additional technical parameters [4]. Thus, machine specific NC programs have to be generated for different machine tools. Due to the missing interoperability between CNC machines, these can be executed correctly only on one kind of machine [5]. In practice, the NC program is generated only for the selected machine to avoid an additional effort.

STEP-NC, was introduced to overcome the incompatibility of NC programs. The aim is to replace traditional G&M code and its several vendor specific dialects. Despite many researches on it, STEP-NC has not become widely accepted in the industry and is still searching its market [4], [6].

In case of changed conditions in the shop floor the queued processes must be reallocated to alternative machines to avoid delays or failures in the following manufacturing steps. It is the task of the operations scheduling and dispatching to determine the start time and sequence of manufacturing processes as well as the allocation of resources. However, it is not possible to reallocate the machines easily, due to the described missing interoperability between CNC machines. This leads to a lack of short-term resource flexibility, which is a major restriction for the operations scheduling and dispatching also in highly flexible production systems.

2.2 Approach for an intelligent manufacturing process planning

This approach facilitates the pursuit of an automated selection and validation of alternative machine tools as a method of prevention. An ontology-based decision-making system identifies all capable machine tools, based on the requirements of the NC program. The machine tool change is approved by simulating the machining on virtual machine tools. The scheduling and dispatching selects the most economic machines with regard to the actual conditions in the shop floor. The early preparations of machine changes increases the resource flexibility without additional human work.

3 State of research

3.1 Basics

Definition of ontologies. In informatics ontologies are recognized as a formal representation model for terms and definitions. They provide a well-defined vocabulary to specify the meaning of elements in a knowledge area. They provide a foundation for a common understanding, for reasoning and knowledge reuse. The components of ontologies are concepts (classes), individuals (instances), relationships and axioms.

In the field of production, the use of ontologies is still a research topic, but the modular design offers a promising potential for the description of different aspects of production systems and the knowledge management [7] [8]. The formality of ontologies enables knowledge modelling that is comprehensible by machines and humans and provides automated conclusions, e.g. the classification of new resources, the composition and configuration of manufacturing processes and resources [7] or the autonomously review of action alternatives [9]. This enables an improved automation or assistance of recurring, but time and cost intensive activities of employees.

3.2 Relevant research areas

The presented approach deals with three research areas: Knowledge modelling of machine tools, selection of appropriate resources and reuse of NC programs.

Ontology-based modelling of machine tools. The knowledge modelling is the critical component for every knowledge-based system. The Manufacturing's Semantics Ontology (MASON) enables the description of relations between product, process and resource [10]. The focus lies on the specification of mechanical work pieces, the necessary manufacturing processes and the capable machines. An example application is the automated determination of manufacturing costs. The Manufacturing Service Description Language (MSDL) by AMERI ET AL. is the base for a standardized description of manufacturing capabilities of suppliers at different levels of abstraction. Focuses are technological aspects in a digital manufacturing market [11].

Selection of appropriate resources. This is part of the computer-aided process planning (CAPP), when it is supported by a planning software tool. These software tools often include macro programming, reuse of templates and knowledge-based searching. However, due to differences among manufacturing shops, the underlying knowledge model has to be customized for each shop floor, which makes these applications inefficient for small and medium sizes enterprises (SMEs) [12]. Approaches for the selection of appropriate resources on a higher level exists in the field of supply-chain-management (SCM). The MSDL was extended for a semantic supplier discovery in a digital manufacturing market [14]. Therefore a *SupplierProfile* describes the capabilities of a supplier and a *Request for Quote* describes the request of a customer. For the improvement of the matching process, AMERI ET AL. extended the Ontology with rules to model human expertise in the field of SCM [15]. SHEA used the MSDL to propose the scenario of a cognitive machine shop. Thereby, the CAPP tasks are implemented in cognitive machines. Each machine "knows" its capabilities and generates a machining plan autonomously including executable machine code and requests for other necessary services to fulfill the demands [8]. CHI proposed a rule-based model for supplier discovery with an underlying ontology-based description of capabilities. The manufacturing suppliers are mainly characterized through the parts and products they produce and there is no direct reference to the manufacturing processes or resources provided by the suppliers [16].

Reuse of NC programs. SCHRÖDER and HOFFMANN proposed a tool to support the user by converting NC programs from one language to another. The parsing of NC blocks is implemented by regular expressions that are saved in external conversation rules files. In this way, different languages for each control can be integrated [17]. A new kind of NC program processor (NCPP) for the integrated control of CNC systems was designed by GUO ET AL. [4]. Standard NCPPs handle only one dialect of G&M code, the presented concept of a NCPP deals with a variety of NC program inputs. Therefore, different NC specifications are stored in a dictionary and are used by the NCPP to interpret the corresponding NC program correctly.

3.3 Preliminary conclusion

The selection of alternative machines should combine technological and economic considerations. Today, technological criteria (machine capabilities) dominate the selection and later economic factors (e.g. actual situation in the shop floor) are not considered due to missing interoperability of CNC-machines.

The existing solutions and research approaches for cognitive CAPP and SCM do not include these holistic considerations [12]. The approaches for an automated supplier discovery or a dynamic SCM reconfiguration are designed for rough requirements and exclude short-term economic factors (e.g. delivery time). In the field of CAPP, only a few researchers have addressed the aspect of automated machine selection [13]. It remains to be said that cognitive CAPP and SCM provide recommendations on the basis of a knowledge base, but the decisions still needs to be verified.

4 Ontology-based decision making system

4.1 Enclosing holistic concept and procedure

In the process planning, the manufacturing orders are prepared as working plans with sequences of manufacturing steps. Relevant for this approach are all machining steps on machine tools. The execution requires the generation of the NC program including raw part design, tool and fixture selection and setup planning (CAM data).

Based on this input information, figure 1 shows the following procedure in the framework of an intelligent process planning. First of all, the decision-making system finds alternative machine tools for each manufacturing step. In addition the system provides the adapted CAM data for each of the alternative machines. The decision-making system may consider the machine tools of one division, the whole factory and even subcontractors. The capable machine tools and their specific adapted CAM data are simulated on a virtual machine tool model to ensure an error free run. If the simulation fails due to collisions or other errors, this information is send back to the decision-making system for improvement. If the simulation is successful the machine and manufacturing data is stored in a repository as approved resource for this manufacturing step. The scheduling and dispatching selects the most economic machine tool, out of all approved machine tools, with regard to the actual conditions in the shop floor. If conditions changes, the scheduling and dispatching reallocates the resources on each manufacturing step. At start of production, the manufacturing process data is sent to the machine control and the setup data to the machine operator.

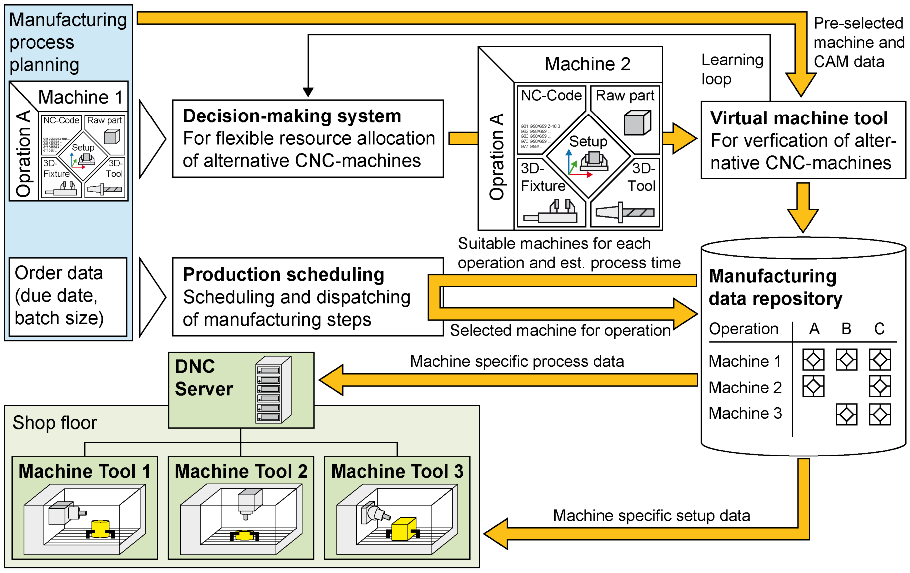

Fig. 1. Aspired workflow enabled by the ontology-based decision-making system

4.2 Overview of the decisions-making system

This paper focuses on the ontology-based decision-making system for the automated identification of capable machines, taking into account different machine configurations and applications. First, all capable machines are searched within the ontology based on the rough process description, derived from the CAM data. In the next step, the specific setup information and NC program is adapted for each machine, to overcome the interoperability. This includes the adaption of G&M code and setup plans for different machine configurations. The next two subsections deal with the underlying ontology of the first step, the second step is not considered here.

4.3 Knowledge model to describe machine tool's capabilities

Top-level concepts. The ontology InVor is the core part of the decision-making system. It contains the specific machine characteristics and the expertise of experts to derive the resulting capabilities [18]. The ontology is described with the Ontology Web Language[1] (OWL), which is a W3C recommendation for the Sematic Web.

There are two sections in the ontology, which describe the basic machine description and the resulting capabilities. The basic machine description corresponds as far as possible to the machine components and auxiliary devices (tools, fixtures). Separate concepts are used to describe the auxiliary devices and the machines' components in detail, like the main driver, magazine, control, table, axes and spindle. Each concept has obligated and optional standard parameter which describe the characteristics of

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1 http://www.w3.org/TR/owl2-overview/

the component (comparable with the master data) and the static relations to other concepts. For example an axis is described by its orientation, traveling or turning range, feed rate and its connection to other axes or the tool attachment. The concepts are used like a template to instantiate individuals that describe concrete machine tools. This is similar to the class and instance concept in object oriented programming.

The top-level concept capability profile describes the resulting machining capabilities and thus the technical suitability to perform a specific NC program. Each machine tool has several profiles that exclude each other, for example, a not-rotating work piece makes better use of the work area. This is expressed by a separate capability profile with a larger work area, if the rotary table is not used. The capabilities of machines with more than one table or with a pendulum mode are described in the same way. The capability profiles are described in the orientation of the axis movements in the G&M code. The basic machine description model does not enable any automatic reasoning of the resulting manufacturing capabilities. The generation of all capability profiles by hand is costly and therefore not an option. For that reason, rules in the ontology InVor describe the externalized expertise of experts, which enables an automated reasoning of the resulting capabilities of a described resource.

Rules integrate expertise of experts. The rules are modelled inside the ontology with the SPIN[2] (SPARQL Inferencing Notation), which provides a RDF compliant representation of rules and constraints on ontologies. This has the advantage that all information and knowledge is stored at the same location. The rules are located in the affecting concepts in the ontology and operate on different levels.
Figure 2 shows the two rule levels and the three stages of the ontology. The rules of the first level are used to enhance the basic machine description model. They cover the mappings between machines, tools and auxiliary devices and the creation of additional parameters that can be derived from the basic machine description.

For example all tools that fit into a specific machines' magazine or spindle are identified and linked, represented by an arrow in figure 2. The link between a tool and a spindle requires only the same type of tool holder; the link to a magazine additionally restricts the size of tools. Whereby, some tools require an empty adjacent pocket and reduce the overall number of tool places in the magazine. Furthermore, the use of certain tools or materials might restrict the feed rate or spindle speed of the machine due to technological limits. These restrictions can be described for generic tool types as dependencies or functions between standard parameters by rules, too. The resulting new parameters in figure 2 complete the basic machine description.
The rules of the second level utilize the enhanced machine description model and add all conceivable capability profiles. These contain all capability parameters that are not fixed (e.g. max. work piece weight of the table) and depend on the different machine configurations (e.g. pendulum mode, setup configuration). The capability requirements for a manufacturing step are derived from the G&M code and the raw part, therefore the description of capabilities is adapted to these requirements. This means that the capabilities profile describes the work piece dimensions and work area in the

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[2] http://spinrdf.org

coordinate system of the NC program and not in the machines' coordinate system. Figure 2 illustrates this by two example profiles with a rotated work piece. Profiles 1&2 are based on the same physical axes of the resource, but the feasible rotation describes an alternative capabilities profile to fulfill the requirements of a specific work piece and NC program. The rules are not machine specific, but contain a filter under which conditions they should be applied. Condition means here: Machine components or characteristics that are necessary to provide a separate capability profile.

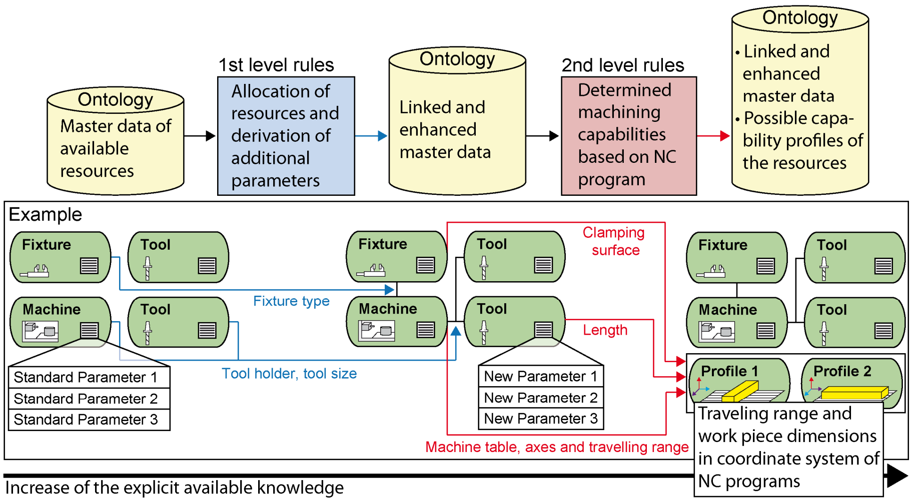

Fig. 2. Transformation of the machine characteristics to the provided machining capabilities

5 Conclusion

Against the backdrop of permanent changes of capacities in the shop floor it is very important to consider the economic efficiency of the previous selected machine tools. The decision-making system and the underlying ontology InVor support the determination of alternative machine tools on the basis of an existing NC program. The enclosing holistic concept provides the automatic arrangement and review of machine tool changes and increases the resource flexibility. In the case of machine down times, the production control is able to reallocate the manufacturing steps to alternative machines quickly and without human interaction. The first implementation has shown that the ontology-based finding of feasible machine changes is possible. Next focus is the integration with the operations scheduling and dispatching module. Experiments of other researchers have already shown that the number of identified suitable resources has a high impact on the efficiency of scheduling and dispatching [19].

The prototype implementation and case studies takes place in an innovation project in the Leading-Edge Cluster "Intelligent Technical Systems OstWestfalen-Lippe" (it's OWL) with DMG MORI and addresses the utilization of virtual machine tools on a cloud platform for the optimization of machining processes [20].

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