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CAD-based automated assembly planning for variable products in modular production systems

Joachim Michniewicz[a]*, Prof. Dr.-Ing. Gunther Reinhart[a], Dr. Stefan Boschert[b]

[a]*Institut für Werkzeugmaschinen und Betriebswissenschaften, Technische Universität München, Boltzmannstr.15, 85748 Garching, Germany*
[b]*Siemens Corporate Technology, Research and Technology Center, Otto-Hahn-Ring 6, 81739 Munich, Germany*
**Corresponding author. Tel.: +49 (0) 89 289 15476; fax: +49 (0) 89 289 15555 E-mail: Joachim.Michniewicz@iwb.tum.de*

Abstract

The paper presents an approach allowing to utilize the flexibility of modular and reconfigurable production systems for the automated assembly of multi-variant products. Required assembly processes as well as valid assembly orders are automatically extracted from the CAD-file of the individual product. Assembly processes are described as skills and are automatically assigned to capable production resources after a simulative verification, generating an optimal assembly plan. The described planning process takes the properties and geometry of production resources, their mutual interactions as well as the layout and feasible material paths of the entire production system into account.

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1. Introduction

Currently the manufacturing industry is facing an increasing demand for flexibility due to the trend of mass customization. The amount of product variants ascends, life cycles fluctuate increasingly and lead times need to be minimized [1],[2].
Despite that, current factories are planned and optimized for specific products or specified product families. The introduction of a new product variant or the integration of a new resource to the production system requires high manual effort and is time consuming [3].
Mass customization and creation of variants is usually achieved during product assembly [4]. Increasing modularization and compatibility of product components enlarges the product range and facilitates the introduction of new product variants and new components. Assembly planning and the selection of the optimal resource configuration however becomes increasingly complex and time consuming [5]. High manual effort is required to validate the practicability of the required production processes with the available resources as well as the selection of an optimal allocation of the resources to the necessary assembly steps [6].
Automated assembly systems are usually used for specific pre-defined tasks. Only a narrow spectrum of the functional range of resources is utilized (e.g. the workspace of a robot in comparison to a repetitive motion or the restriction of a gripper to one gripping point of one specific part) due to manual efforts for planning and validation of the required processes. Furthermore the control code for the entire production system needs to be developed, tested and implemented manually [7].
In order to facilitate the determination of product requirements towards necessary assembly processes, different approaches for the automated analysis of CAD-Models of the product assembly have been introduced [8-12]. However, the presented methods do not take the generation and selection of an optimal assembly plan for a modular and reconfigurable production systems into account. The solution space, constraining alternative possible allocations of the required processes to available resources, varying material flows as well as different valid assembly orders are not taken into consideration sufficiently.
Methods for automated production planning in flexible production systems depend upon various manual inputs in

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order to define the process sequence required by the product in the specific description language of the system [13-18]. The effort necessary for creating each product-individual model in production with small batch sizes is not taken into account. Usually only one valid process sequence is given, disregarding the flexibility of the product to different feasible assembly sequences. The factory topology has to be entered manually in a specific modelling language, further increasing required expert knowledge and planning efforts in flexible production systems.

The presented paper suggests a skill-based approach for solving these problems. The overall system has been introduced in detail in previous publications [19-21]. The system minimizes adaptation effort due to common software tools widely used for input of product (CAD software) and production system data (programmable 3D factory simulation), which are then used to automatically generate the specific models needed for further computation. The focus of this paper are the efficient automated generation of the product requirements from CAD-Data taking the factory layout into account as well as a detailed validation of the overall system.

The paper is organized as follows: section 2 gives a brief overview of the system architecture and functionality. Section 3 specifies the methodology behind the automated CAD-File analysis. Section 4 contains the validation of the overall system. Section 5 discusses achieved increases in flexibility and adaptability. Finally, section 6 summarizes the paper and provides an outlook on future work.

2. System architecture and functionality

2.1. Tasks and Functional Primitives

The basis for the flexible allocation of resources to required assembly processes are *Tasks* and *Functional Primitives (FP)*, allowing a solution independent representation of requirements and abilities. They are stored in an extensible library. Elemental processes like movement, gripping and releasing are modeled as FP, which are derived from a widely accepted guideline [22]. Tasks represent more complex recurring processes often found in assembly like "assembly of two parts", "screwing" or "handling of a part". Tasks are modeled as sequences of FP. The sequence of FP in a Tasks represents logically linked actions like the alternating closing and opening of grippers as well as movement while handing a part from one robot to another (see Fig. 1). However the FPs are parametrized individually for each product-specific sub-step during assembly.

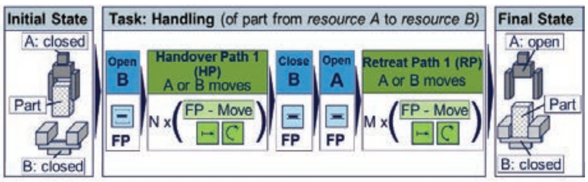

Fig. 1: Functional Primitives contained in the Task "Handling". *Handover Path* describes the movement during the approach of the resources, while *Retreat Path* describes the collision free retreat movement after the handling operation.

2.2. Modeling of the production system

In order to facilitate the search and allocation of feasible resources, a model based on functional primitives representing the overall abilities as well as feasible material paths through the production system was introduced [19-21]. The model is called *Production Graph (PG)* (see Fig. 2d) and is automatically generated from digital models of available resource, placed in a 2D- or 3D simulation model of a production system (see Fig. 2b). In order to facilitate the use of the system, the PG is generated from unaltered simulation files of common simulation programs. Consequently changes to the production system are performed easily by adding, removing or moving resources in a familiar interface. The PG is updated automatically.

The digital model of each resource contains individual representations of the properties, abilities (stored as FPs), constrains and its geometrical workspace. Digital models for different grippers, robots, conveyors and screwdrivers are implemented.

Vertices in the PG represent workstations with their corresponding abilities represented as Functional Primitives, which result from the individual resources available in a workstation. Edges represent valid material flows between vertices. Vertices and edges are generated automatically by detecting overlaps between workspaces of the different resources (e.g. overlapping workspaces of two robots generate an edge; a robot workspace overlapping reachable tool generates a vertex).

2.3. Modeling of the product requirements

The product requirements as well as feasible assembly orders are modeled as a directed graph called the *Augmented Assembly Priority Plan (AAPP)*. The AAPP consists of vertices, representing Tasks, and edges, modeling feasible assembly orders. Tasks contain a sequence of FPs. Value adding Tasks like "assembly" or "screwing" consist of two initial subassemblies which are joined together to form one new subassembly. The output of the final Task is the finished product (see Fig. 2c).

The generation of the product requirements from CAD files (see Fig. 2a) is explained in detail in section III. Without knowledge about the production system, only value adding assembly processes can be extracted from CAD-Files of the product to be assembled. In this state AAPP is solution neutral. The combination of the PG and the solution neutral AAPP in order to allocate all resources optimally and generate the factory specific AAPP is briefly introduced in the next part.

2.4. Automated allocation of resources

In order to generate a valid assembly plan, containing the optimal allocation of resources to assembly processes required by the product, initially all value adding processes are considered. For the two initial subassemblies in each Task pairs of adjacent vertices in the PG are searched, assigned and added to the Task description in the *factory specific AAPP*, following the assumption that both subassemblies must be held by individual resources whose workspaces overlap. This allows the feasibility test of all value adding processes as well as the detection of missing or insufficient abilities.