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Planning and developing cyber-physical assembly systems by connecting virtual and real worlds

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Abstract

In this paper a methodology for supporting the assembly planning engineer is given which connects the virtual planning environment with a real assembly system. The method starts with product and process analysis, continuing with a capable assembly module selection while several validations are conducted. A reference model, as part of the methodology, is used for clustering information in the different steps. The virtual planning model is connected with a real assembly system which allows an automatic model update, providing the planner with the latest system configuration. While operating the assembly system the connection is simultaneously used to derive a product memory which guides the product through the assembly. The methodology is implemented by tools of the digital factory which are connected with modules of cyber-physical assembly systems.

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Keywords: Assembly System Planning Methodology; Cyber-Physical Assembly System; Reference Model; Assembly Capabilities

1. Introduction and state of the art

Shortened product life cycles and continuous changes on existing product variants are challenges for today's production engineers [1]. To overcome these challenges flexible production systems have to be developed faster and with the ability to reconfigure which allows an adaption to upcoming changes, e.g. of the product. These systems are also able to produce different product variants at the same time [2]. The reconfigurability can be achieved through the introduction of versatile and cyber-physical assembly systems which imposes an ability to reconfigure on the mechatronic and software side [3].

Assembly is a part of production after manufacturing. In manufacturing raw materials are machined whereas in assembly parts are attached one-by-one to form the final products [4]. These products are created in an assembly system, often consisting of several stations which form an assembly line for a specific product range [5]. It is recognized that the allocation of assembly operations including feeding of parts and joining processes, etc. at several stations, make the planning of assembly systems much more complex than manufacturing systems [6]. The assembly planning engineer is responsible for the development of an assembly system which is able to produce a wide product range efficiently. Moreover, the assembly planner has to determine if a product can be assembled on the existing system or if modifications have to be performed. Modifications like reconfigurations and integration of new resources are done by the system operator when the system is in operation. These modifications are sometimes done by the operators without coordination with the planning engineer which might result in conflicts when outdated data of the assembly system is used for planning.

Due to the growing number of parallel produced product variants and more frequent product updates, the decisions must also be made more frequently. Until now, a standard object-oriented description does not exist for the objects and their capabilities within assembly which allows a connection between virtual and real assembly to keep both sides updated.

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On the German national Plattform Industrie 4.0 the Reference Architecture Model Industrie 4.0 (RAMI4.0) is in development [7]. The objective of RAMI4.0 is the establishment of a standard for the connection of elements in the physical and virtual world. A three-dimensional model is used to describe the different perspectives on elements, the product life cycle and the functionalities of elements within the factories. The product is considered as one element within the factories on the hierarchy levels but the assembly processes and requirements are not considered in detail so far. The RAMI4.0 approach considers existing standards on the communication layer like OPC UA and developments on the end-to-end engineering like AutomationML.

The AutomationML consortium is developing a framework based on XML which intends to cover the complete engineering process of a production system on the software side [8]. AutomationML focuses on the development process of automation system engineering and models objects of the automated system in a tree based format. Nevertheless, the description of various component capabilities is not supported by AutomationML. Moreover, the product with its assembly operation is not focused and thus only modelled with low granularity which is inadequate for assembly planning. Better opportunities for assembly planning are provided by product lifecycle management (PLM) solutions which use databases to store consistent data and allow access from multiple sides.

From the software and PLM side, supporting tools of the digital factory gain more importance in order to control the wide range of product variants and their information. The aim of digital factory is the holistic planning, evaluation and ongoing improvement of all main structures, processes and resources of the real factory in conjunction with the product [9]. The existing data models of the digital factory already enable structuring of product, process and resource as well as the definition of the assembly sequence [10]. Nevertheless, product and resource properties and their relation cannot be described as Brunner et al. provide a concept and first implementation to overcome this problem [11]. Another data model concept is provided by Angelos et al. which assigns capabilities to two different tiers. The assembly task requires a capability and the resource provides a capability [12]. Both concepts focus on the validation of capabilities in the virtual world but do not detail how the comparison is done and do not consider the data exchange with the physical system in reality.

Thus, this paper presents an object-oriented reference model for describing product and process requirements as well as resource abilities with the same capabilities. The focus is on the assistance of the assembly planning engineer and information provision. For assisting the planner and to describe the data exchange between virtual and real world a planning method is introduced which uses the reference model for clustering the relevant planning information. For the validation of the methodology a demonstrator scenario is given and the reference model is implemented in a tool of the digital factory.

2. Methodology for planning cyber-physical assembly systems

The planning methodology consists of a reference model and a method. In the reference model important facts between objects in the scope of assembly planning are described by standardized elements and thereby serve as a reflection of the complete system. At the same time the reference model provides the framework within the method can operate and the information between virtual and real planning environment can be exchanged. The requirements for the assembly are described from the view of the product which moves through the assembly and which has requirements such as material feeding as well as process performance in the individual assembly processes.

Whereas, the planning method describes the required steps for the development of the assembly systems and with the help of the reference model in background. The planning method supports the planning of products at an assembly line but the information can also be used for start-up and operation of the real system.

Hereafter, first the structure of the reference model and then the method is described. For the clear presentation of the reference model the UML class diagram notation is used [13].

2.1. Reference model providing a standardized framework

Before describing the individual classes of the reference model in detail within this chapter, a brief schematic overview of the complete model is given at the beginning in Fig. 1. In the upper level of the model a connection between product and process takes place. The pieces of information of product and process are then brought together in an individual product bill of process (BOP). This BOP is subsequently detailed with resources that are used for assembly, resulting in a plant BOP. In the lower level the assembly operation is derived from the process. These operations are connected with the item as well as with the assembly module and subsequently with the property as described in the schematic model. With this connection and thus the consistent description of requirements as well as abilities a comparison and a resource allocation can be conducted.

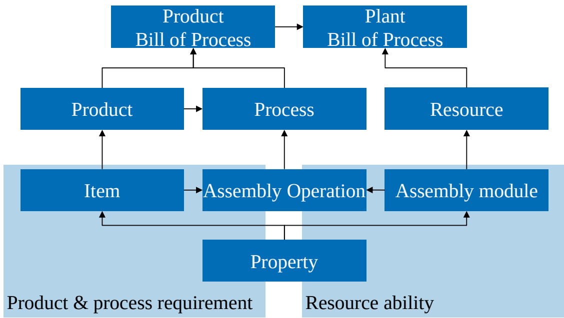

Fig. 1. Schematic class overview of the reference model

The product consists of several assembly items which are united in the bill of material as illustrated in Fig. 2. The assembly items are divided in subassemblies, parts and