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Concept for the Configuration of Turnkey Production Systems

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Abstract

Shorter product lifecycles and increasing individualization of products lead to the necessity for a reoccurring process, which includes the selection and configuration of production systems to provide a system that produces the product. Especially in fast developing countries like China, the offer for this knowledge can hardly supply the demand. In order to solve this, this paper presents a systematic approach in the form of a multi-stage process. In the first stage, a configuration logic maps product requirements with the properties and specifications of production machines together with equipment and matches them using a uniform data information model for both products and production modules. In the second stage, the turnkey production system is set up, commissioned and operated based on the Industrie 4.0 administration shell. The presented approach has been prototypically implemented on an online platform and demonstrated on a real production system using a new product that has been integrated into production.

Keywords: Manufacturing system, Customisation, Modular design

1. Introduction

Lot sizes of individual products are decreasing in production. This is the result on the one hand of the increasing individualization of these products and on the other hand of generally shorter product life cycles. In view of this development, production systems must also be available in less time and reconfigurable for new production tasks just as quickly in order to be able to produce flexibly and cost-effectively down to lot size 1.

First and foremost in rapidly developing countries such as China, there are many young companies that develop innovative products, especially in the areas of environmental protection and digitization, which are high on the agenda of China's strategic plan "Made in China 2025" [1]. Digitalization and electric mobility in the field of environmental protection as decisive technical changes pose significant challenges for production technology [2]. The market uncertainty associated with disruptive technologies requires great flexibility and scalability on the part of manufacturing companies. However, the supply of experts and knowledge on how these new products can be quickly put into production and produced in a scalable manner is far from sufficient to cover the large demand.

Therefore, an approach is necessary which systematizes the description of production systems, machines and components with uniform semantics. A similar description of products to be produced then enables a comparison between the product to be produced and the available production modules as well as between the production modules themselves. The approach needs to be applicable across manufacturers and, in addition to the requirements of the product to be produced, also take into

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account the user's specifications with regard to, for example, the maximum budget or the intended production volume. In addition to the configuration of a new production system for a new product, existing machines and components should also be taken into account. For existing machines and components, there is therefore a need for reconfiguration of these existing systems, for example for the introduction of a new variant of a produced product.

In this paper, the authors introduce and validate a concept how production system can be configured semi-automatic to simplify and speed up this process. Therefore in section 2 the state of the art is discussed, followed by the actual concept presentation, how turnkey production systems can be configured semi-automatic, in sections 3 and 4. Section 5 describes the current state of the validation of the concept. The paper is concluded with a summary and an outlook in section 6.

Nomenclature

RAMI 4.0	Reference Architectural Model Industrie 4.0
IMSA	China Intelligent Manufacturing System Architecture
OEE	Overall equipment effectiveness
CM	Condition monitoring
CBPC	Cloud-based production control
TCO	Total cost of ownership

2. Foundations and state of the art

2.1. Architectural models for Industry 4.0

In order to describe and structure relevant information of products as well as production systems, architectural models are an important foundation. A decisive representative of these architecture models is the 'Reference Architectural Model Industrie 4.0 (RAMI 4.0)' model. The concept of the asset administration shell represents an important basis for the structured description of a digital representative of products, machines and components [3]. Another significant approach from China is the "China Intelligent Manufacturing System Architecture (IMSA)" [4]. For international standardization, there is also a working group Intelligent Manufacturing/Industry 4.0 of the Sino-German Standardization Cooperation Commission, which has resulted in an alignment report for both approaches [4].

2.2. Production system configuration

Due to its growing importance, production system configuration is also a major topic for more and more approaches from research and industry. Existing approaches and developments from both research and industry regarding production system configuration are shown in [5].

Some of the approaches deal with the configuration of production systems, but without building it up on product or customer requirements and taking the respective interdependencies into account. For production system configuration, Graupner et al. use a building block system with which individual production systems can be compiled from individual machines and equipment [6]. The approach of Novák et al. includes a simulation of the manufacturing system to simplify and speed up the design and redesign of the manufacturing system [7]. However, both approaches do not base their configurations on a product to be manufactured and do not consider interdependencies between product and production system.

Further approaches are limited to a specific field of application or the selection of the basic production technology. Although Schäffer et al. base their configuration of industrial robot applications on the product and offer the user individual customized solutions regarding customer requirements and product, the user platform is limited to individual robot applications and does not cover comprehensive production systems [8]. Mayr et al. also consider the interdependencies between the product and the production system in their concept for an integrated product and process development for electric drives [9]. The concept, which aims to find the best overall solution for the user's requirements, is however limited to the field of electric drives.

There are also numerous approaches on the part of the product and the product features aiming to make products automatically machine-readable, especially in the area of feature recognition for CAD-files. One of the main approaches covers the comparison angular relationships between connected outer surfaces and determine their convexity or concavity. After having analyzed the outer structure of an individual component, rule based algorithms can categorize which set of surfaces represents a specific CAD-feature. The drawback of these algorithms is mainly their inability to be used accurately for all features, especially when there is an overlap of multiple features. Other than that, free form surfaces are also rather hard to analyze in this way. Furthermore, often only the shape of the feature can be recognized, the way of processing the feature has yet to be determined. Newer methods include machine learning based approaches with the algorithm training on synthetically created CAD-training data files to recognize particular features. In these approaches the CAD file often gets preprocessed in a way that creates a mesh of the CAD and then voxelizes the volume. Only then the voxelized geometry gets analyzed for feature classification. The drawback is the strong dependence of the accuracy of the shape of the 3D-geometries on the size of the voxels. Smaller voxels also lead to exponentially higher computational times, which make this approach only feasible to a certain degree. For a more detailed overview of feature recognition algorithms, see [10] and [11].

In summary, there are a variety of approaches that deal with production system configuration, some limited in their application fields, and many approaches dealing with feature recognition. However, none of the existing solutions covers a comprehensive production system configuration that takes both customer and product requirements into account. Therefore, an approach for the manufacturer- and application area-spanning configuration of production systems on the basis of a product to be manufactured and under consideration of the user requirements is lacking.

3. Approach based on open platform

In order to make interactions between the product to build, the user requirements and the machines and equipment machine-readable, a semantically uniform data model with a modular structure is used for products as well as production modules. This also enables the automation of the configuration process from the initial setup of the production system to operation. The uniform data model serves as the basis for the comprehensive and manufacturer-independent description of components, machines and entire production systems.

The uniform data model consists of various attribute categories for products and the production modules consisting of the available machines and equipment:

- mandatory core attributes such as unique identification and the respective class (product, system, machine, tool etc.)
- optional class-specific attributes such as machine type, machine interfaces or product material and geometry

Based on the uniform data models and to realize a systematic and partially automated configuration of a turnkey production system a multi-stage process based on the product to be build has to be performed [5]. The multi-stage process begins with the extraction of the features of the product to be produced, is shown in Figure 1 and is explained in more detail in the following chapter. Defined interfaces between the listed process steps allow entry and exit before and after each process step. For example, if required, only the production system can be configured to identify the required production modules such as equipment for a new product without subsequently deriving the control.

In addition to static information in the module descriptions of the machines and equipment, attributes for the operation of the system, such as operating time, are also provided. With the help of these attributes, machine and manufacturer independent monitoring and analysis are also possible, which are based on the module descriptions of the machines and equipment and for which the module descriptions serve as an enabler. Potential monitoring and analysis use cases are overall equipment effectiveness (OEE) or condition monitoring (CM) applications.

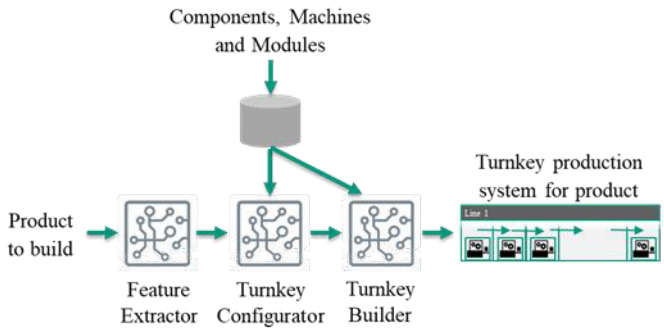

Fig. 1: Configuration process

4. Concept for the configuration of Turnkey Production Systems

4.1. Extraction of product features

As part of the feature extraction, properties of the product to build, such as drill holes or millings, which are decisive from a production point of view, are identified and modelled. This means that the complete CAD model needs to be disassembled into atomic components. The knowledge how these components are connected is available in the model (e.g. two components connected by two screws which are two further components). In order to automatically analyze CAD-files that might be presented to the platform in an exchange file format, such as STEP, the authors explored approaches in the field of automatic feature recognition.

In this work the authors apply a rule based approach that also takes product manufacturing information into account. It is also planned to integrate consulting services on the platform, to deal with unexpected geometries and more detailed manufacturing information that cannot be conveyed through a single CAD-file. The output of this method is a list of concrete features which is mapped to a visual representation of the product on the platform. A feature here can for example represent a hole with a certain diameter, position, trajectory, tolerances, surface quality, etc. The feature-list is then mapped with matching manufacturing processes. For this purpose, a process library is being added to the platform, encompassing all possible relevant manufacturing processes. To deal with the challenge of multiple possibilities to process a single feature, all possible processing options are examined and in a later step evaluated.

The resulting detailed process-lists in turn can be used to describe the requirements on tools and machines that are used for processing. E.g. a hole-feature can best be manufactured by a drilling process using a drilling tool that matches geometry in diameter. The tool itself has to have an interface with a fitting machine. The machine in turn has to match other requirements coming from the feature- or detailed process list – e.g. matching workspace and product dimensions. The configuration logic of this concept will be discussed in more detail in the next chapter.

4.2. Development of a configuration logic for the composition of production systems

Based on the feature extraction described in chapter 4.1, the multi-level configuration process is carried out. As shown in Figure 1, the process begins with the extracted features of the product to be produced, which serve as requirements for the production system to be configured, like the specifications defined by the customer.

The customer specifications, which include the target production volume, the total planned production system budget and the required availability, are compared with the respective attributes of the production modules and thus reduce the possible solution space. At the same time, the available machines are compared with the process list and the machines that can carry out the extracted processes with their respective specifications are identified. The machines are also tested for suitability with regard to product characteristics such as size and weight. In a further step, the available components are compared in order to check, for example, whether suitable tools are available for a drilling process of a certain length and diameter in addition to the necessary machine. Finally, the components, tools and machines identified with regard to their suitability are compared with each other in terms of their interfaces in order to again select combinations that work with each other.

The result of these comparison processes is a list of possible machine combinations for all extracted production processes of the product. In order to give the user a manageable number of options, the configuration algorithm suggests the best combinations with regard to certain criteria, comparable to a vehicle navigation system. While a vehicle navigation system suggests options such as the fastest, most efficient or most scenic route, the configuration logic suggests combinations such as lowest cost of ownership, best performance and most efficient operation. With regard to lowest cost of ownership, the optimum is calculated from the total sum of the attributes 'purchase price' and 'operating costs' of all necessary machines and equipment. Any existing machines and equipment of the user are included in the calculation with a purchase price of zero and are thus prioritized. Dynamic attributes such as the availability of a machine are constantly updated in the model descriptions of the production modules during system operation and can thus be included in any reconfigurations.

After the user has selected the preferred system combination, a list of all selected production modules with machines and components as well as the associated linking sequence and the workflow is generated. This serves as the basis for an optional order of the selected system of the user. On the one hand, this serves as the basis for an optional order of the selected system of the user, on the other hand, it can also generate an exemplary machine layout with the associated workflow on the basis of the shop layout given by the user.

4.3. Cloud-based control architecture

In the steps described in the previous sections, all necessary information and processes for manufacturing the product were collected and as an output machines have been ordered.

Next, the machines have to be setup to manufacture the product accordingly. To realize this, a system with a cloud-based architecture for controlling the entire manufacturing process of a product has been realized. The system consists of a central cloud component, referred to as cloud-based production control (CBPC), the gateways and the machines themselves. The CBPC is designed to operate in the cloud and the gateways to run locally in the factory or directly on the machines. The architecture of the system is shown Figure 2.

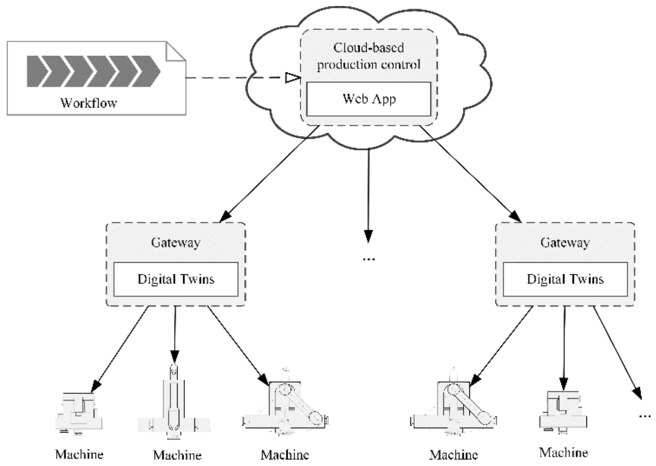

Fig. 2: Architecture of cloud-based production control

In order for the CBPC to control the machines, the machines have to be known in the CBPC. For this, a self-description of the machine is needed. Such a machine self-description is implemented in Ecplise Foundation's Vorto and can be generated from the machine module model [12]. The Vorto file contains all necessary information about the machine type such as capabilities, status information and parameters for controlling the machine. This data model of the machine has to be installed on the respective gateway so that a digital twin of the machine can be created in the CBPC as soon as a gateway is online for the first time. Afterwards, the gateway can automatically register the machine when it is turned on and start to continuously send all relevant information via the gateway to the CBPC and to receive commands for controlling the machine.

Once the system is ready as described above, the control of the actual manufacturing process can start. The basis for the production control is a workflow as described in chapters 3 and 4. The workflow contains all the information about the sequences of machines and operations required to manufacture the product to build.

When the workflow is loaded into the CBPC, the machines from the workflow have to be assigned to the real machines. If automatic mapping of the machines is not possible for any reason, the mapping has to be done manually via the CBPC. After the workflow has been deployed on the CBPC, the manufacturing process can start. The CBPC controls the execution of the process steps. If a machine is occupied or not available, the further execution is interrupted until the required machine becomes available again.

An advantage of the cloud architecture is that all machines and workflows are centrally managed. However, direct access to the machines is only possible via the gateways. The CBPC sends the commands from the workflow to the gateway. Each workflow is executed with a role and the gateway can check if the corresponding authorization has been assigned to the role used. This separation also enables new service models in the field of 'Industrie 4.0', where the workflows are managed and provided by third parties and a factory only provides its capacity as machines.

5. State of implementation

The current setup of the platform consists of a website, a nosql database server, and a span of loosely connected IoT-platform solutions. The website serves as a connecting point between customer businesses, vendors and service providers. Here, the customer can upload his product to be produced in the form of a STEP file and have it analyzed as described in Chapter 4.1. The website then shows a 3D-view of the product. By hovering over the product, single features of the CAD are highlighted and the matching processes are described simultaneously on the website. After giving some additional information (e.g. quantity requirements) the customer can now query the configuration of his or her production system. This triggers the algorithm described in chapter 4.2, where the requirements coming from the extracted features and processes are matched with the available module models, representing tools and machines, from the database. The available matching configurations, of which there might be plenty, are then rated and thus ranked according to some customer specific optimization criterion (e.g. lowest total cost of ownership – TCO, highest performance, etc,). This way, for further simulations only a few solutions have to be calculated. The website now allows the customer to visualize the proposed production system configurations. Therefore, a web based 3D-visualization tool has been implemented that serves two purposes: First, it demonstrates the production system layout of machines, enables early evaluations and readjustments by the customer but also shows the suggested production process as well as transportation processes in detail. This is accomplished by reading out the individual production system configurations and querying the database for the selected module models. The modules then, if not otherwise specified, are arranged in a layout that puts the machines according to their processes in a logical order. When prompted the simulation for visualization shows the production process of a single workpiece. This may involve multiple machines using different tools as well as transport processes between machining processes. The second purpose for this visualization is, that it can later serve as a digital twin of the production system, right after its physical installation. Using the cloud-based control architecture, real-time process data coming from the connected physical machines but also notifications coming from real time data stream processing (e.g. regarding predictive maintenance) can then easily be visualized in the digital twin model.

6. Conclusion and outlook

With shorter product life cycles production systems also have to be developed and set-up faster. Furthermore, increasing individualization makes lot sizes even smaller leading to the necessity of more flexible and highly reusable production systems. The demand for rapidly available and scalable production systems for new products exceeds the supply of experts and knowledge enormously, especially in rapidly developing countries such as China. In this context, an approach was presented on how production systems can be systematically configured and commissioned on the basis of the product to be produced and the requirements of the user.

Future research will deal with the extension and detailing of the model structures for the production modules in operation in order to be able to incorporate even more dynamic operating data into the configuration or reconfiguration process. This will also be followed by filling the production module database with further modules from various manufacturers and the associated extended tests and validation with selected users, manufacturers and system integrators.

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