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Automatized Setup of Process Monitoring in Cyber-Physical Systems

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Abstract

This paper presents a method to reduce manual planning effort for introducing and initializing process monitoring on existing assembly lines. The focus is set onto the reduction of manual initialization processes by automatically identifying devices and their process abilities, as well as relevant process data. Individual assembly processes often change due to new product variants, and therefore the entire planning of a process monitoring has to be manually adapted. Combining existing expert knowledge of assembly processes and requirements with modern communication interfaces and intelligent data processing, automated installation effort for monitoring processes promises high potential.

Keywords: process monitoring; cyber-physical systems; quality management; assembly features

1. Introduction

Process monitoring becomes continuously more important for quality management due to more complex and diversified processes, products and production lines [1]. Individualized products with small lot sizes and shorter product-life cycles force companies to introduce new product variants and assemble them on existing production lines with little lead time [2]. Being able to assemble different product variants on a production line that can change its devices increases the complexity and can therefore, result more likely in process errors [3,4]. The consequence is an enhanced necessity to implement a continuous and adaptable process monitoring system which focuses on the relevant process data [3]. Information on alternating processes have to be generated, sorted and analyzed as fast as possible in order to be able to use the flexibility of a reconfigurable production line and decrease potential process errors.

Today the adaption of a monitoring system is accompanied with manual and time consuming effort due to the heterogeneity of the devices and processes [5]. Customized products in small lost sizes provoke higher manual effort due to constant awareness of product specific processes which need to be monitored. In combination with increasing heterogeneity of resources in assembly lines, this induces a complex setup of process monitoring. Constantly improved computer performance and intelligent algorithms are able to analyze huge amounts of process data but rely on their quantity and quality. A key challenge hereby is to identify and gain the required process data from resources which are able to provide these [6,7].

The presented paper introduces a skill-based approach for an automatized setup of process monitoring in reconfigurable assembly systems. By expanding the virtual representation of the product, process and production system and their communication among each other, inspection planning and even process monitoring can be made adaptable.

The structure of the paper is organized as follows: section 2 gives a brief overview on how process monitoring can be planned and how Cyber-Physical Systems (CPS) can be used to automatize planning processes. Section 3 presents the challenges in planning process monitoring. Section 4 displays a vision on how process monitoring can enable flexibility in the assembly. Section 5 gives an overview of the system architecture and its subsystems. Lastly section 6 summarizes the paper and provides benefits of the developed system.

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2. Related work

2.1. Methods for introducing process monitoring

Re-engineering is often the solution to identify critical processes. Hereby inspection characteristics and possibilities to distinguish them can be determined to ensure the quality of the process and thereby product. Different methods in quality management, such as the FMEA (Failure Mode and Effects Analysis), are being used to prevent failures before they occur by identifying reasons and measures [8]. Computer-aided quality tools (CAQ) often relay on methods like FMEA to improve the inspection planning and therefore, identify processes which need to be monitored. The identification of potential failures in processes, its reasons and relevant process data involves manual and time consuming effort and expert knowledge.

Due to an inconsistency of process data and its description the introduction of process monitoring often involves manual adaptations, and is therefore time and cost consuming. Before monitoring specific processes, an analysis of potential process failures and its relevant data has to be identified. Methods such as FMEA and DoE (Design of Experiment) are used to gather sufficient expert knowledge. The two main steps are: identifying the process features to be monitored (1) and monitoring the feature with the correct device (2) [8,9]. In comparison to a Computer Aided Inspection Planning (CAIP), where the focus lies on the generation of an inspection process, the monitoring of a process is supposed to supervise an existing process [10]. Therefore, no additional process is planned or generated.

In manufacturing the integration of process monitoring is already widely used to understand machine and process behavior [3]. A machine tool with its known relevant process data eases the introduction of process monitoring. Flexible and reconfigurable production systems on the contrary impede the introduction due to manual adaptions of the relevant process data for process monitoring [5].

2.2. Automated generation of assembly processes

Assembly processes are defined during the assembly planning which nowadays is forced to be more flexible and responsive due to more complex products and production systems. Methods for the automatic generation of assembly processes have been developed that are based on the virtual communication and analysis of resources and products [11,12]. CPS contain and process data intelligently so that devices (Cyber-Physical Device; CPD) can communicate with each other [6,13]. For the generation of assembly processes the requirements of the product to be assembled, as well as the abilities of the available devices, have to be taken into account. Automatically generated assembly processes contain the task, the device (e.g. screwdriver) and station (e.g. worktable) which executes the task, the necessary assembly paths and additional nonvalue handling and transport tasks [11].

Different methods for the automatized assembly planning in correlation with CPS exist but neglect the automatized planning and setup of process monitoring. The focus on Michniewicz [11] approach lies on the generation of assembly sequences and processes to identify the material flow in production systems and suitable resources to fulfil specific processes. CPS are hereby used to generate virtual representations by analysing and simulating data such as geometrical and functional information they inherit. Virtual representations of the product to be assembled and the devices executing the processes are utilized and enriched through paired parameter comparison and multi-body simulations. The consideration of critical process parameters which need to be monitored and their semantical description is left out. The papers of Michniewicz and Hammerstingl [11,14] both consider abilities of resources in an existing production system but do not take in regard the necessity to monitor processes.

The planning of process monitoring needs manual effort to identify processes to be monitored, as well as to determine the available and relevant process data on an existing production line. Different types for process monitoring have to be manually identified, evaluated and generated (e.g. “direct” - primary purpose is for monitoring, e.g. sensor; “indirect” - primary purpose is not for monitoring, e.g. power of an engine) [1]. The planning of process monitoring is done alongside the assembly planning by identifying the assembly processes, its critical parameters and existing resources on the production system.

3. Challenges

Challenges in today’s process monitoring result from alternating processes which will occur even more in the future due to the increasing complexity of assembly processes (provoked by individualized products, flexible and reconfigurable production systems) [6]. Wang et al. [15] approach this by presenting a modular functional block concept where assembly processes are defined. Through functional blocks the assembly plan can be sent to the specific resource which executes the task. An automatized allocation between the process to be monitored and the required resources to execute this task is not examined. Hammerstingl & Reinhart [12] address the hardware-independent communication of resources and data in a production system through a semantic description called “skills”. The skill-based approach provides a possible solution, so that devices can be described directly through their hardware-independent functionalities [16]. This allows an automatic allocation of devices.

A flexible adaptability of process monitoring and an automatic communication channel towards the specific devices are needed. An essential challenge is the identification what process data is needed and what can be received with the existing devices. Direct monitoring through sensors is often seen as a laboratory setup whereas indirect monitoring using forces, torque etc. are more applicable [1]. The identification which data needs to be acquired by what resource, how does it correlate with the process to be monitored and how is it related to the resource executing the task are challenging factors [1].

4. Vision

The presented method aims at an automatized setup of process monitoring where critical processes and devices for supervision are automatically identified including the relevant process data. Through a product specific and automatized identification of processes to be monitored, even small lot sizes and high product variants can be monitored efficiently. This increases the quality assurance while reducing planning and initialization effort. Semantical descriptions of the processes to be monitored and the skills of the devices including their technical realization enable a general planning of process monitoring. Automatically identifying the necessary data to be monitored and the devices gaining, leads towards an automated initialization of process monitoring. Besides the reduction of work load for the planning and initialization of process monitoring, recommendations are able to point out necessary adaptions such as additionally needed sensors. This increases the efficiency of process monitoring.

5. Method for automated planning of process monitoring

5.1. System overview

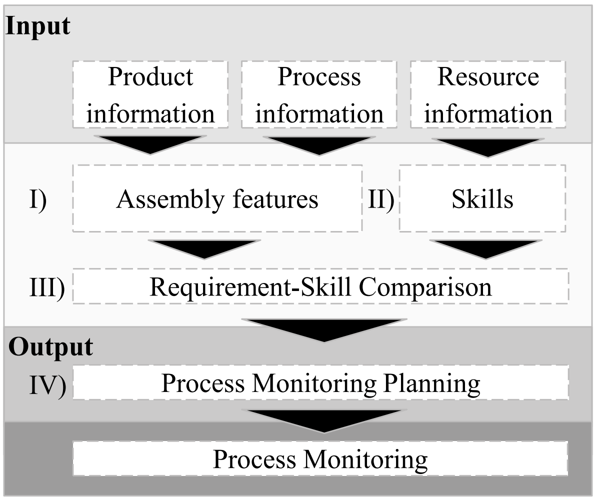

Fig. 1. Overview of the system for automatic process monitoring planning – including 4 subsystems (I – IV).

The system contains four steps and generates a feasible setup of process monitoring based on an existing assembly plan (Fig. 1). Implemented in a software it serves as an assistant to automatize the setup. (I) In the first step of the method an analysis of the virtual product is needed to identify assembly features relevant for monitoring. By analyzing the CAD model, critical assembly features (e.g. surfaces between two parts or screw parameters) are identified which have to be monitored. Additional features such as PMIs (Product Manufacturing Information) in relation to the necessary assembly processes are therefor used. The focus lies on an automatic classification of specific assembly features in relation to the correlating product parts and assembly processes. This is one of the advantages of semantical approaches. Information of production resources are being described hardware neutral which allows the categorization of information.

(II) In a second step, information of the resources from the assembly line is being analyzed and an ability model depending on its monitoring skills is automatically generated. The ability model represents all the possible monitoring skills of all devices, e.g. “distance checking” or “temperature checking”. (III) The matching process between the assembly features and device monitoring skills plays the key role in this method. By comparing those domains (assembly features and device skills) the coverage for adequate process monitoring is analyzed.

(IV) The fourth step allocates the necessary devices and their process data to the specific assembly features of the product. In case no match can be identified, necessary device reconfigurations are generated through recommendations so that the monitoring can be executed. After the configuration the process monitoring can be initialized and started. The data now gives the opportunity for further analytics tools to start the monitoring.

5.2. Automatic identification of assembly features to be monitored

Input to the system in 5.1 is an already generated assembly plan including the product and existing process information (e.g. CAD model, constraints). The entire geometrical information of each part, as well as its constraints, exist in the CAD file. Additional information such as features can further describe the product and its manufacturing requirements [3]. By combining information gained from the CAD model with the assembly processes, assembly features are automatically be extracted. Analytical and shape based approaches exist for the CAD feature recognition and are able to extract this information [17,18]. Furthermore, assembly features, generated by the designer, are automatically identified and extracted.

Expert knowledge connects information about critical assembly processes and features inside the CAD model. The expert knowledge is being derived through an ontology. This allows structuring and classification of the different assembly features and their product and part specific critical parameters.

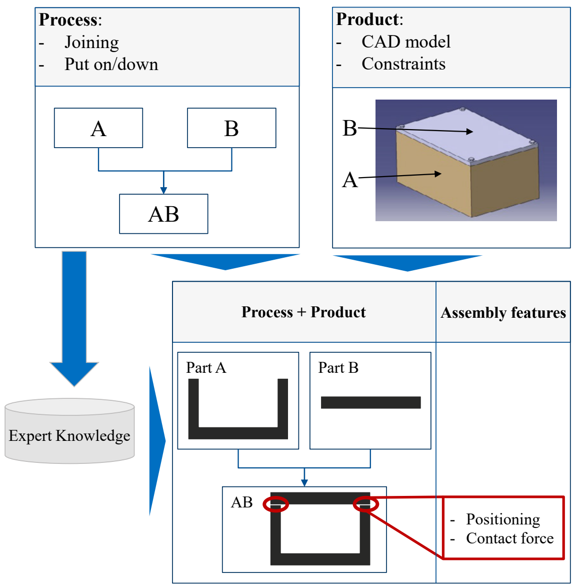

Fig. 2. Information model of a product to be assembled, process information and its assembly features (to be monitored).

Knowledge about assembly processes can hereby be applied to new use cases. For example, correct positioning without collision is a key aspect when joining two assembly parts. The contacts of the surfaces are critical for the execution of the process. In Fig. 2 an enhanced information model illustrates the combination of the product and process information. The outcome of this subsystem are product specific assembly features which are categorized due to their processes and evaluated through expert knowledge. The automatically generated semantic descriptions of processes to be monitored can further be used to identify fitting devices and process data.

5.3. Identification of monitoring skills of cyber-physical devices

In order to match the assembly features to be monitored with the existing devices of a production line, the ability model has to be generated (specifically for monitoring skills). CPS are able to give information on the current production line in real-time [14]. This can be used to automatically generate an ability model specifically designed for monitoring skills. Michniewicz and Hammerstingl [11,14] present methods how the ability model can be generated with a focus on the automated assembly planning. The generation of an ability model for process monitoring, on the other hand, has not been examined. Information of the technical functions and interdependencies have to be taken into account so that resources and their ability to monitor critical parameters can be defined.

The automatic identification of resources and their correlations to describe specific monitoring skills has to be expanded. These aspects are not covered by the approaches of Michniewicz and Hammerstingl [11,14]. Their focus lies on the assembly planning and reconfiguration of production systems. Monitoring skills, especially during execution of assembly tasks, as well as data acquisition in real-time, are not further described. Fig. 3 presents an enhanced information model focusing on monitoring skills.

Skills can take different roles depending on the view of the system. Therefore, the current of the feed axis drive of a robot can have an influence on the robot's pose accuracy and thus affect the ability to grip a component for assembly. The

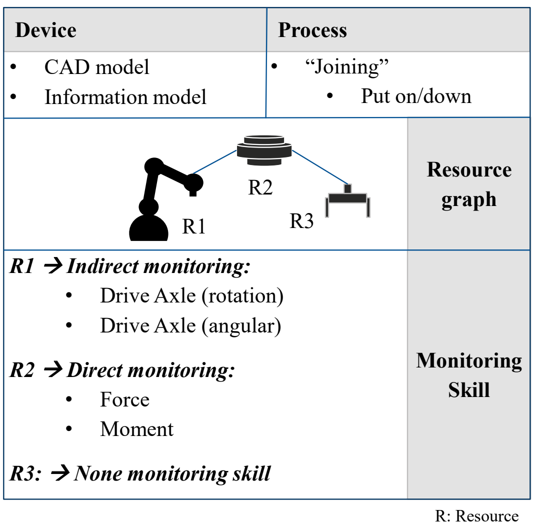

Fig 3. Information model of a device with its monitoring skills and process information.

accuracy through a power monitoring is an indirect skill because its primary purpose is not for monitoring. A force movement sensor is able to monitor the force which is a direct skill. Considering direct and indirect skills for monitoring enhances the matching between assembly features to be monitored and monitoring skills on an existing production line.

5.4. Comparison between assembly features and device skills

The matching process is the core of the method. The generated semantic descriptions of the requirements of the assembly features and the monitoring skills of the devices are compared in this step. The assembly plan allows the allocation of the assembly processes to their devices on the assembly line. So that the following task is to assign the specifically identified assembly feature to the devices and their skills for monitoring. In Fig. 4 this is illustrated by a comparison between specific monitoring requirements (assembly features to be monitored) and skills.

The matching process is separated into a semantic matching and a quantitative analysis. The semantic matching provides a general coverage if the assembly feature can be supervised. The process data acquisition must match the process monitoring to check the specific assembly feature. The quantitative analysis goes into detail whether sufficient data can be gathered to monitor the assembly feature.

If by any chance the monitoring of a process cannot be executed by the devices existing on the assembly line, a reconfiguration will be proposed so that the correct data can be gained.

5.5. Process monitoring planning

After the automatic configuration, of assembly features enriched with semantic descriptions ("monitoring requirements") and their automatically assigned resources ("monitoring skills"), the process monitoring can be planned. After the allocation of the devices the necessary data for the assembly feature monitoring must be set, as well as its threshold values. This information is gained through the matching process and must be approved by a user. The allocation of devices to specific assembly features gives the opportunity to reduce the potential process data to be monitored and allows further analytics tools to start monitoring immediately. Process monitoring which is specific to process and assembly features can hereby be initialized automatically.

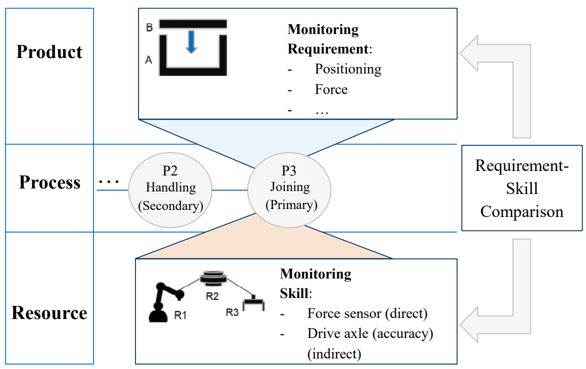

Fig. 4. Comparison between monitoring requirements and monitoring skills.

In combination with intelligent data analytics tools this method provides an adaptive and flexible system that enables a product individual process monitoring, and therefore the management of its quality.

6. Conclusion and Outlook

The presented approach takes skill-based description of devices and product requirements towards a new level. Different methods for automatizing assembly planning, as well as planning reconfigurations, have been developed. By taking “monitoring skills” into account, the possibility to reduce manual effort through automatizing the planning of an introduction for process monitoring can be achieved. Information gained from this method can be used to adjust the production system and initialize a process monitoring. The result is an improved usage of flexible and reconfigurable production systems in assembly. Adaptive and automatized monitoring of assembly processes allows an enhanced responsiveness for the introduction of new product variants on existing production systems. The concept outlines a method to increase the flexibility of reconfigurable production systems by automatically identifying and matching processes to be monitored and resources (i.e. process data) for monitoring.

Further work must be carried out in the automatized recognition of assembly features through process specific expert knowledge to define monitoring requirements. It has to be analyzed how assembly features can be described semantically and categorized to identify necessary process data. Therefore, next steps for this concept are the elaboration of the presented subsystems and development of a prototypical demonstrator. Solution modules for the CAD feature recognition, the generation of the assembly line skill model and their matching process will be implemented in software. The use case of a product to be assembled on an assembly line is currently under construction which will serve as validation.

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