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Intelligent devices in a decentralized production system concept

Iris Gräßler[a], Alexander Pöhler[a,*]

[a]Heinz Nixdorf Institute, Paderborn University, Fürstenallee 11, 33102 Paderborn, Germany

* Corresponding author. Tel.: +49-5251-606262; fax: +49-5251-606268. *E-mail address*: alexander.poehler@hni.upb.de

Abstract

Current manufacturing research topics, like Cyber Physical Production Systems, Industry 4.0 and machine learning, deal with the enhancement of machine control systems to create self-controlling production systems. This paper shows an approach to add supplementary information acquisition and processing tools to former executive units in order to enable decentralized decision-making. Therefore computers with additional sensors and communication devices were added to each component of a production system in a production laboratory. This change from a production machine to a self-controlling cyber-physical device is illustrated through the implementation in a milling station consisting of an industrial robot, a milling machine and a logistic station. The paper deals with the distribution of tasks to different component types and also with the connection to employees by such a decentralized system.

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1. Introduction

Recent developments in production and information technologies described by subjects like Industry 4.0, cyber-physical systems (CPS), Internet of Things (IoT) and Industrial Internet establish new ways production devices are controlled, connected and operated. [1] Industry 4.0, which term represents the fourth industrial revolution, stands for the ongoing penetration of ICT and their interconnection with each other [2]. Productionwise this interconnection is described through the horizontal and vertical integration of enterprises. The vertical integration describes the connection of systems and services in an enterprise among hierarchical instances. This includes mainly the connection of all involved components in the production planning and control process. The horizontal integration stands for the connection of systems and services along the value chain beyond interfaces to customers and suppliers. This interconnection of all systems and services enables devices on the shop floor to gain holistic information about themselves locally. Therefore in an Industry 4.0 production scenario the tasks of production devices can be enhanced from former executing to actually self-controlling. This idea of a self-controlling production system is the main contribution of Industry 4.0 in a production-wise context. This proposed interconnection in Industry 4.0 is also a main element of CPS, respectively CPPS (cyber-physical production system) in production context. [3]

CPS can be seen as enhancements of embedded systems. [4] Whereas embedded systems are not necessarily connected to other systems, CPS are just created through the interconnection among cyber-physical devices. CPS present a new kind of integration between physical and computational elements. The virtual space, which is enriched in a CPS through information exchange among cyber-physical devices and with other systems and services via the internet, is connected through actors and sensors with the physical reality of the CPS. Each device of a CPS thereby is a participant in this system and contributes to it by sharing information and generating an interface to the real world. Its task is to control or observe physical production processes through sensors and actors. With the aid of sensors CPS are able to directly collect, process and evaluate data, while actuators allow them to interact with the real world and digital communication facilities allow them to exchange information with other CPS or services. [5]

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The implementation of CPPS will lead to significant changes especially in manufacturing processes and production control systems. The most significant features of CPPS are connection to computational services and among CPPS itself. Connections with services help CPPS accessing information available in software systems (like ERP, MES) and the Internet (for example for material and energy prices). Through the connection of multiple CPPDs, the data exchange among them and connections to superordinate collaboration platforms, CPPS can gain holistic information on their given tasks. Therefore CPPS are qualified to take decision and execute them self-contained. [6] This concept assumes that no superordinate controlling system, which controls all elements of the production system is necessary in such an environment. This concept leads to an idea of dividing manufacturing processes into certain decentralized controlled autonomous production systems. [7] Connected to this idea of CPS is a self-control of each element in order to use the advantages given by the connectivity and the local available information. This idea of Industry 4.0 and CPPS therefore both question the dogma of a central controlled production planning and control system.

This idea of a distributed production control is assimilated by several subjects particularly Holonic Manufacturing Systems (HMS) and (delegate) Multi-Agent Systems (MAS) [9]. This paper focuses on intelligence in the procedural execution of a production process, which is permeated by CPPS. The planning part, which result from negotiations among all systems respectively orders from superordinate systems, is not considered in this paper. [10] gives an overview of the connection between CPPS and distributed systems, which are mainly based on holonic manufacturing architectures. The actual process execution can also greatly benefit from an implementation of modern production, information and communication technologies and a self-determined decentralized execution of the process by the devices themselves. These benefits are illustrated in this paper by an implementation in a milling station exemplarily. Idea of this paper is to illustrate an upgrade of process execution by making a production device "intelligent". Intelligent hereby means that the device is able to interact with its environment autonomously. This interaction involves learning from expected and unexpected events and adapting to changes of it. Therefore an intelligent process execution depends on several

factors, which the device needs to acquire by itself. Additional sensors, actors and the ability to communicate independently therefore need to be implemented in the device. [11]

In the following section the state of the art of production devices and connected subjects like IoT Industry 4.0 are

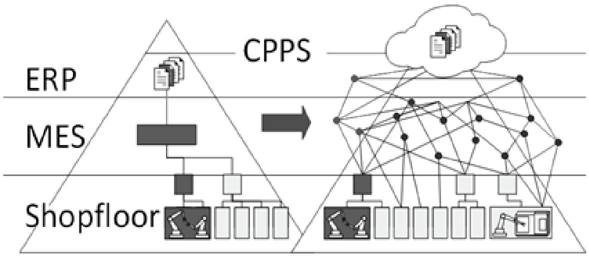

Fig. 1: Influence of CPPS on production planning and control [8].

examined. Subsequently the changes between the former system and the new system are explained by an examination of a milling station. In section 3 the former milling machine and its integration in the system is described and the changes according to CPPS are presented. Based on these changes a model for the whole system is developed in section 4. The paper concludes with a summary and outlook in chapter 5.

2. State of the art of production devices

Newly developed devices related to CPPS, Industry 4.0 and IoT are based on currently emerging technologies. These emerging technologies change both the structure of the system, as well as the execution procedure. Whereas in Industry 3.0 production machines where equipped with a computer in order to repeat a pre-defined process over and over, this dogma of automation shifts to an adaptive and more intelligent handling of this procedures.

The idea of these modern devices is based on several technologies. For the interconnection among the devices mostly characterizing for such systems are the subjects MAS, service-oriented architecture (SOA), cloud computing and wireless technologies. As already mentioned CPS and Industry 4.0 open up possibilities regarding a distributed control via MAS. MAS is widely explored in the field of decentralized production control [12]. For distributed respectively holonic manufacturing systems the MAS was enhanced to a delegate MAS concept by [13]. As already mentioned through the dissemination of the automation pyramid such kind of distributed production control is combined with an implementation of Industry 4.0. SOA is an architectural approach for the development of distributed, heterogeneous software systems. SOA have advantages especially according to adaptability, simplicity and flexibility, which are major aspects of Industry 4.0. [14] In a manufacturing context cloud computing is seen as a way to store data on a server on the internet, but also to offer production capacity in a market place in form of Manufacturing as a Service (MaaS). [15] Wireless technologies in an IoT-production environment offer the possibility to physically detach for example sensors from the actual production device. Wireless communication plays a key role in the realization of CPPS [16]. Through connections over the internet with sensors and other devices CPPS are able to gain information about the environment and thereby adapt and optimize themselves. For example automated energy-intensive production devices are able to adapt their schedule according to energy costs.

For creating the intelligence in the device it needs to be enhanced to be capable of measuring its own status and also learning from behavioral aspects. [17] for example describes an intelligence device as an active object. It needs to be capable to operate in a complex, changing environment. The identification of the environment and collecting and processing data according to it is very difficult. [18] The elaboration of intelligence in a technical context can vary greatly. [19] describes four key features of intelligent systems. Adaptiveness for an autonomously interaction with the environment, for the system to consequently evolve in it. Robustness to operate in a dynamic environment and to handle uncertainties. Anticipation to choose strategies and user-friendliness in order to adapt to a user-specific behavior.