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Analysis of control architectures in the context of Industry 4.0

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Abstract

Industry 4.0 is a current research topic in the field of production engineering. One common characteristic of Industry 4.0 is decentralization which can be implemented by a decentralized production control. Several researchers have already addressed decentralized production controls. This paper focuses on the characteristics of Industry 4.0 as well as decentralized control approaches and hierarchies. Different properties of approaches and architectures are compared to the objectives of Industry 4.0. Based on this comparison conclusions are drawn about how different architectures suit Industry 4.0, and need for action for the development of production controls of Industry 4.0 is derived.

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Keywords: Production planning; Scheduling; Planning; Industry 4.0

1. Introduction

As a response to the current challenges in fast changing environments, the concept of Industry 4.0 has been discussed in research for several years. With this concept, several objectives are pursued. One major objective is to improve the cost situation of a company by decreasing the costs per piece [1]. Moreover, the production systems should become more flexible regarding customer demands [2]. This results in small batch sizes which increases complexity. To manage this complexity another objective of applying Industry 4.0 is to decentralize the structures of production [3]. Consequently, Industry 4.0 focuses to improve the competitiveness by reducing costs and increasing flexibility in decentralized production systems to offer customized products, which is an advantage in satisfying customer markets. Therefore, a high level of productivity has to be reached to stay competitive.

The motivation to decentralize production systems by applying decentralized production control is not new, but was discussed already many years ago. Due to this history, an analysis of the control architectures for production control is conducted with respect to their suitability for Industry 4.0. To this end, the terms Industry 4.0 and related cyber-physical production systems (CPPS) are analyzed to investigate their backgrounds and to determine their main characteristics. Subsequently, in chapter 3 the theory of centralized and decentralized production planning and control is presented and the different control architectures are explained. Finally, conclusions about the control architectures with respect to Industry 4.0 are derived in chapter 4 and an outlook for future research is given.

2. Industry 4.0

Despite the high relevance of Industry 4.0 in production research and the high number of publications on this topic, Industry 4.0 has not been clearly defined [4]. Moreover, the understanding of what exactly pertains to this topic differs and the affected research fields differ. In contrast to the past three industrial revolutions, for the upcoming fourth revolution no single technology has been identified that triggers Industry 4.0. Instead, it can be described more precisely by a conjunction of many technologies – both existing and new – which now work together [5]. This combination of technologies leads to new opportunities and applications in production systems.

Despite the lack of a standard definition, as previously mentioned, there are technologies and characteristics that clearly belong to Industry 4.0. One of the key technologies in the fourth industrial revolution is the internet [6]. In a more general way, Industry 4.0 can be described as a conjunction of

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information and communication technologies (ICT) with production systems [7].
One of the key enablers of Industry 4.0 are cyber-physical systems (CPS) [8]. CPS describe the amalgamation of embedded systems and the internet to connect physical objects [9]. If these systems are applied in production systems, the products, the machines and other facilities become smart to some degree, then cyber-physical production systems arise [8]. Thereby, the machines and corresponding facilities of the production systems as well as the products are interconnected with each other through the internet and information can be exchanged. The connection through the internet allows on the one hand more flexible interconnections of machines or other facilities and offers a higher degree of flexibility as an ad-hoc connection is enabled [6]. On the other hand, it enables a data exchange in real-time so that information is available to every element at all times.
To realize CPPS, several developments must be made to today's production systems. An important prerequisite is that the elements of a production system need to become smart [7]. To this end, the elements will be equipped with memory processors and the ability to communicate, and are additionally equipped with sensors and actuators [10]. Sensors enable the machines to collect information about their environment or particular conditions that have to be monitored, whereas actuators offer the opportunity to interact with the production system.
In addition to the ability to process information, elements also need to be clearly identifiable. The identification of every element within the production system enables targeted communication and data exchange of the machines. Moreover, the elements need to be aware of their own conditions. Each element must contain information about its original, current and final condition, and include steps that allow autonomous control of production [8].
Another important characteristic of Industry 4.0 is the already mentioned ability to collect and use a large amount of data [11]. The act of data collection alone does not offer advantages. Instead, to make use of the data and generate additional value, it is important to analyze and process the data in real-time and separate unimportant and important information [6]. Industry 4.0 offers potential to analyze the data of the production system for patterns which can either be used to make better forecasts for the future, or to improve decision making by discovering weaknesses and taking into account the system's current status [12]. Moreover, monitoring enhances the understanding of the machines in the production system or the system itself [13].
Hence, data collection and processing is a big advantage of Industry 4.0, as it provides a better database for decision making. This is especially true of the opportunity to constantly gather refreshed data, which offers new applications and possibilities for decision making in production systems.
The properties of Industry 4.0 respective to CPPS described so far lead to another one of its central characteristics, decentralization [14]. Smart elements, which are able to make decisions on their own in combination with the information of the production process, enable an autonomous, self-controlled production done by machines and products. Decentralization is pursued to manage complexity and requires a complete change of the current centralized production control.

3. Architectures for production planning and control approaches

Despite the theoretical benefits for decentralized production control, today's production control is predominantly centralized [15]. The characteristics of the varied production control styles will be subsequently described to better understand the way they work.

3.1. Centralized production control

Centralized production planning and control is characterized by the fact that all decisions are made by one centralized control unit, which plans and schedules different production orders and hands them over to the machines [16]. To handle the complexity arising from comprehensive decisions, the decisions are made in several steps. The hierarchical control architecture does a partition of the overall problem into smaller subproblems over the hierarchical levels [17]. Thereby, information pathways over the hierarchical levels are well defined, namely that commands always flow downwards in the hierarchy and sensory data flows upwards [18].
The commands sent by the control unit mostly concern determining scheduling, quantity and capacity planning. Therefore the centralized approach requires stable and predictable conditions. The schedules fixed by the central control unit are handed over to the machines at the shop floor level, which execute the defined schedules without any further adjustment. Furthermore, the machines give feedback to the central control unit. If changes occur for any reason, the central control unit conducts a complete replanning with updated data. In this process, it is necessary that the unit is continuously provided with updated data [18].
The implementation of the centralized approach as done by a hierarchical architecture is shown in fig. 1 on the left side. This part of the figure illustrates the elements receiving commands from the control unit to just execute the commands. Thereby, the elements are dedicated to several defined tasks like machine control or gathering information from the sensors.

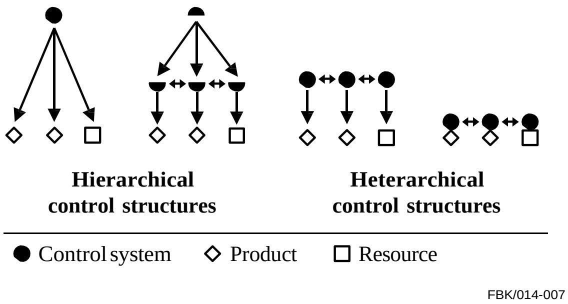

Fig. 1. Types of control architectures based on [19]

The strengths of a centralized approach and hierarchical architecture are their access to global information, which is a basic requirement for global optimization, and that all information can be retrieved from a single source [20]. But the single source and the centralized approach also have disadvantages. Although centralized planning leads to precise