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Implementation of an adapted holonic production architecture

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Abstract

Recent developments in information and computation technologies open up possibilities for the practical implementation of flexible, self-controlling production systems. The decentralization of existing production systems and their control plays a decisive role in creating the demanded flexibility and achieving an overall self-controlled system. The basic concept of the decentralization of production systems was set by the paradigm of Holonic Manufacturing Systems (HMS). In a HMS an element (holon) of the production system works autonomously with its own schedule and properties. Just through the cooperation with other holons central tasks of the production system are determined and subsequently executed. In this paper the flexibility and self-control of the production system was applicated through the distribution of decision-making by adding supplementary information acquisition and processing tools to former executive units. The previously procedural connection of the machines was dissolved and replaced by a peer-to-peer communication protocol. Superordinate controlling units, mostly PLCs, were abolished and instead decentralized controlling agents were implemented. The automatic control of the entire system is reached just through the communication of all devices, a machine-based scheduling and additional monitoring agents. The underlying architecture is based on Holonic Manufacturing concepts including order agent, machine, resource, product, logistic and supply holons. In this paper the adapted architecture is presented and subsequently the practical implementation in a research laboratory is described.

Keywords: Holonic manufacturing system; Production system decentralization; Industry 4.0 implementation

1. Introduction

Holonic manufacturing systems (HMS) symbolize a productions systems with a holarchical architecture in order to provide flexible and reconfigurable production systems. [1] The first architecture of such a holonic system was presented by Christensen [2] in 1994. The application however is currently more relevant than ever through recent developments in production and automation research [3, 4]. Each unit of a HMS is represented by an autonomously working holon. In order to fulfil the tasks of the production system, the holons need to collaborate with each other. For this collaboration multi agent systems (MAS) are used. This paper is based on a general holonic production architecture, which is adapted in order to create a completely distributed and thereby decentralized production system. In a production system the main task of the controlling units is to allocate resources and to distribute jobs. Whereas in traditional central control systems jobs are assigned to units based on certain properties, in decentralized controlling approaches this assignment process needs to be carried out through a communication among the systems themselves.

Nowadays through recent developments in production and automation research, described by subjects like "Industry 4.0", [5] "Cyber-physical Production Systems" [6] and "Industrial Internet", the concept of decentralized production architectures and especially HMS experiences a new relevance. Industry 4.0 describes a scenario where the production system shall control itself through the interconnection of the units in the production system. This units can be machines, production equipment, work pieces as well as warehouse and transportation systems. Through the interconnection among the systems and through its versatile character, the production system shall be flexibly reconfigured regarding current tasks. [4] This idea of a self-controlling production systems corresponds to a decentralized

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controlling approach. Cyber-physical Production Systems (CPPS) also support this change to decentralized decision making and heterarchical structured production systems. CPPS enhance production systems with additional information gathering and processing tools and communication devices. Just through the interconnection in a CPPS, the data exchange and connections to superordinate collaboration platforms, CPPS shall gain holistic information on their given tasks. [7] To use the advantages given by an implementation of CPPS and the connection among them, a decentralization of the currently superordinate control system is needed. This interconnection between holons and cyber-physical systems is presented in [19].

This paper describes an approach where an adapted holonic production architecture for a completely distributed production control was implemented in a production laboratory. The adaption of the holonic architecture stems from the idea of distributing all production control elements to physical entities in the production system. Thereby the idea of CPPS to enhance production units with computational intelligence and create a self-controlling network can be achieved. In order to achieve such kind of decentralization of physical entities a distribution of superordinate production controlling elements need to be performed. This paper is organized as follows. In the next section the related work to HMS architectures and decentralized production system approaches is discussed. In section 3 the adapted holonic production architecture and subsequently in section 4 the application of the architecture and findings are described. The paper concludes with a summary and a brief outlook in chapter 5.

2. Related work

The structure of a manufacturing system is defined by the composition of the physical elements and the distribution of software elements. In HMS these detached elements are called holons. A holon is defined through the combination of its software module and physical entity. Each holon can act autonomously, that means it is able to make decisions self-contained and can communicate interactively with other holons. The holonic manufacturing system consortium has defined the following terminologies in order to describe HMS [1]:

- Holon: an autonomous and cooperative unit of a manufacturing system for transforming, transporting, storing and/or validating information and physical objects; consists of an information processing part and an optional processing part.
- Autonomy: the unit's capability to control the execution of its own processes self-contained.
- Cooperation: possibility to mutually take decisions
- Holarchy: mixture of heterarchy and hierarchy. A holon can consist of other holons and therefore build an inner hierarchy.

Frameworks for HMS were part of several research projects. The most common framework for HMS is PROSA, which was defined in [1]. PROSA contains the following holon classes: resource holon, product holon, order holon and the staff holon. Resource, product and order holon are the basic holons for production control. In order to produce a product, information among the basic holons needs to be exchanged. The product holon contains all product-related information, the information of the resource holon is needed for matching product with process information in order to allocate and execute the production process. The order holon contains all logistical information like properties and restrictions of the order. The staff holon is often needed for the execution of an order, but regarding the framework it is used as an advisory holon. In [17] PROSA was revised through the ARTI reference architecture for a broader application beyond manufacturing systems. ARTI generalizes PROSA by indicating four kind of holons: Activities and Resources and their types and instances. For the interaction between holons and allocation the NEU Protocol is used [18]. [22, 23, 24] describe other holonic production architectures. In the following description of the adapted holonic architecture PROSA, as the most common architecture, is used as comparison to show differences to existing holonic manufacturing architectures. In order to create the distribution to physical resources mentioned in section 1, superordinate planning agents need to be distributed to actual resources.

This distribution of all production controlling activities to physical production entities shall serve the vision of a decentralized CPPS network. Control approaches for HMS usually include MAS, respectively DMAS [20], which serve as a superordinate controlling structure. Leitao [8] compares in his survey about agent-based distributed manufacturing control different architectures. [9] presents an architecture for a software-centric metamorphic control systems for dynamically reconfigurable distributed multi-sensor-based holonic systems. [10] proposes an architecture for a single holon. The holon consists of a necessary information processing part to communicate with other holons and for example GUIs and an optional physical processing part, which contains the interface to a real system (e.g. transport or machine system). Both parts are connected through an Intra-holon interface, which thereby connects the “real” world with the computational “virtual” world. HMS-frameworks already contain negotiating agents. The PROSA-framework with an included scheduling of the machines has already been implemented, as shown for example by [11, 12]. [13] also shows an approach for scheduling in a PROSA-holonic manufacturing systems using the open-control concept. A dynamic scheduling approach, which is also utilized for HMS, is illustrated by [14]. It also contains a dynamic task allocation mechanism combined with machine scheduling in an agent-based HMS. [15] applicates dynamic scheduling to an HMS as interconnection between task and processing holons. In the following these controlling agents shall be coupled to entities of the production system. These entities shall create hierarchical decision-making structures by themselves. Thereby the holarchical concept of HMS shall be reached.

3. Holonic production architecture

In this paper a completely decentralized production architecture for HMS is presented. In chapter 4 the implementation of this architecture into a production laboratory is described. In the PROSA-framework the control of the production system is reached through the interconnection of resource holon, order holon and product holon [1]. The