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Innovative control of assembly systems and lines

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ABSTRACT

The increasing demand for flexibility and reconfigurability of assembly lines generates new challenges for the control of these lines and their subsystems, such as robots, grippers, conveyors or automated guided vehicles. Also new requirements for their interaction between each other and the environment as well as with humans arise. On the other hand the rapid change of information and communication technology opens new potentials for innovative control. Due to the high degree of interconnection between controllers, actuators and sensors, the classical automation pyramid is replaced by networked structures with a higher degree of flexibility, but also higher complexity. This trend is supported by the ability to collect and process data within cloud environments, the rapid increase of computational power of decentralized and embedded controllers and the high potential of machine learning for automation. This keynote gives an overview of innovative approaches in ICT and robotics for flexible control and automation of assembly lines and systems.

1. Introduction

Current production systems are facing an increasing demand for highly customized products. At the same time the market competition leads to the requirement of cost efficiency. These two goals of both customized and economic production need to be addressed for a successful future of the manufacturing industry. Not only the manufacturing companies themselves but also the equipment suppliers, IT suppliers and suppliers of software in this field are affected by these future requirements.

1.1. Motivation

Assembly systems for customized and economic production are facing increasing demands for flexibility and reconfigurability, reusability and changeability [15,16,79,203,204]. In order to meet these requirements, there are various challenges and changes that must be addressed for assembly systems. Major influences are

- increasing complexity of automated assembly systems,
- planning and integration of assembly systems and lines within the Digital Factory,
- integration of flexible and intelligent robotics in assembly,
- demand for flexible human–robot interaction,
- integration of complex sensor systems such as imaging sensors for in-line inspection and control and
- need for adaptive control and automation solutions.

All these points define a close relation between assembly equipment and industrial IT-systems, for which a development push can be observed due to the various developments in the field of Industry 4.0, such as Cyber-Physical Systems (CPS) or cloud technology.

Control technology for assembly lines and systems is a field where the influence of changes in information and communication technology (ICT) represents a huge potential for flexibility and reconfigurability. This will lead to

- use of flexible and autonomous machines and devices (flexible grippers, cooperating robots etc.) managing a high variety of parts,
- modular control software, capable of being integrated into a variety of shop floor control systems,

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- intelligent control systems utilising information from sensors, exhibiting automatic decision making and monitoring functionality and
- open communication architecture, allowing the transparent integration of new manufacturing components and their automatic operation.

Major influences from ICT for control of assembly lines and systems can be foreseen due to the following influences

- rapid change of former control and communication structures originally based on “automation pyramid” design (ISO TC 184/1988; ISO 16484-2/2004),
- growing importance of event based control strategies and systems based on IEC 61499 in order to reduce complexity,
- diffusion of Ethernet-based fieldbus structures such as EtherCAT [45] and IP-based networks,
- developments in wireless communication systems such as 5G and Tactile Internet,
- developments in the context of Industry 4.0 (cyber-physical systems, cloud technology, digital shadow) [114],
- development of innovative Computer Aided Control Systems Design (CACSD) tools including structured design and testing solutions based on both, simulation based and formal verification methods,
- diffusion of software standards for industrial communication interfaces such as OPC-UA or MQTT [123],
- Open Source controller environments and libraries such as the Robot Operating System [139],
- standards in automation planning environments such as AutomationML [4] and
- the integration of artificial intelligence into industrial robotics.

This leads to the hypothesis that changing production environment and requirements in combination with rapid developments in the field of information and communication technology as well as innovative robotics, actuator, sensor and control systems and digital factory solutions change the way assembly systems will be developed, integrated, controlled and reconfigured during their life cycle. The goal of this keynote is to reveal the opportunities from developments in ICT and robotics for the challenges and requirements of future assembly (Fig. 1).

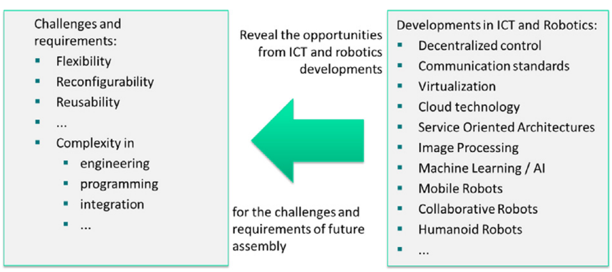

Fig. 1. Goal of the keynote.

2. Control and ICT structures for assembly

Computer control of manufacturing systems has been the focus of extensive research over the last decades. Advances in microprocessor, computing, networking and interfacing technologies have improved capabilities of industrial automation and control systems substantially over this period. However, these control systems are proprietary and still have problems in areas such as interoperability, scalability, and lack of standard user interfaces. The state of the art in control architectures and communication interfaces shows the potential for advances related to these challenges based on standardized and modular system components.

2.1. Control architecture spectrum

The conventional way of controlling the complexity of manufacturing machines in a modern factory is to distribute control instructions through a hierarchy of control computers. This hierarchy is hard-wired; hence reconfiguration of the factory requires physical wiring changes and/or manual reprogramming for controllers. The era of such manufacturing systems with hard-wired interconnection of manufacturing cells is passing and will be gradually phased out, because conventional manufacturing systems are insufficiently flexible due, in part, to their rigid system control structure.

When considering the structure of a control system, one of the main goals is to achieve a design that is flexible enough to adapt to the changes under a real-time manufacturing environment. Ideally, the control system should have this flexibility embodied in its design. When changes do occur on the shop floor (e.g., the addition or deletion of equipment), changes do not have to be made to the control software, or the changes that have to be made are minimal. A decentralized approach involving a number of interacting decision-makers in place of a single centralized one can help satisfy this requirement.

The spectrum of decentralized control systems [187] is illustrated in Fig. 2, which has the following features:

a.) Hierarchical decomposition: decomposes a system into smaller subsystems that have weak interactions with each other.
b.) Oligarchical approach: has communication paths that are less rigid than in previous case.
c.) Heterarchical approach: is a completely decentralized approach. The individual controllers are assigned to subsystems and may work independently or may share information.

Generally, the hierarchical approach to large-scale control systems involves decomposing the overall system into small subsystems that have weaker interactions with each other and also lower degree of cooperative autonomy. On the other hand, the heterarchical approach supports higher degree of autonomy, but it may take more time in decision-making, especially when a large number of control nodes are concerned.

Control architectures for real-time distributed systems need to meet a number of requirements, such as autonomy, reliability, fault-tolerance, real-time constraint, interoperability, and reconfigurability. A continuously changing environment requires an adaptable and continuously evolving control system and its control architecture. A partial dynamic control hierarchy hybridizing both hierarchical and heterarchical architectures can offer reconfigurability and better system performance than either extreme of the spectrum [187].

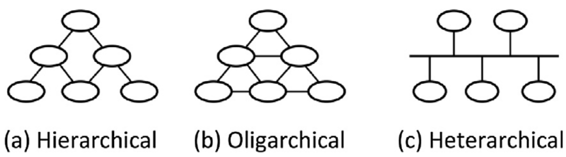

Fig. 2. Control architecture spectrum [187].

2.2. Distributed control systems

Modern assembly lines control systems have to properly cope with rapidly changing production requirements as well as with complex automation tasks. Therefore innovative control architectures and methods are mandatory.

As a matter of fact, nowadays, there are not universally accepted reference models, standards, methodologies and tools for assembly lines and systems control solutions development, maintenance and reconfiguration. Thus, many different methods and technologies are adopted in industrial applications, and many different new approaches and solutions are proposed in recent scientific literature [27,79]. As the state of the art in research control