Agile Automation Systems Based on Cyber-Physical Systems and Service-Oriented Architectures

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Abstract. Nowadays, manufacturing companies have to face increasing challenges to keep pace in our globalized world. The key enabler to fulfill the rising demands is an industrial automation system that supports dynamically changes of the manufacturing equipment and the automation software with low effort. Since current automation systems aren't able to meet these requirements, we need significant changes. Therefore, we present our vision of the automation network that is based on the concepts of Cyber-Physical Systems and Service-oriented Architectures. For realizing this vision we point out which aspects and influencing factors have to be taken into account and propose approaches for a gradual implementation.

Keywords: Industrial automation, SOA, Cyber-Physical Systems.

1 Introduction

Production is facing dramatic changes over the next decade. The worldwide markets demand for new goods in ever shorter time leading to shorter product life cycles mostly combined with an increasing product complexity. Additionally, the customer is asking for a high product quality at lower and lower prices. To keep pace with global competition, manufacturing companies have to adapt their production planning and their manufacturing plants in increasingly shorter time cycles to a wide-range of influencing factors. Therefore, highly adaptive, flexible, and reconfigurable production plants are needed. The key enabler for realizing organizational and technical adaptions dynamically and with low effort is a suitable automation system of the production plant. However, current control structures in industrial automation don't meet the requirements for realizing such agile automation systems.

This paper describes a new control paradigm based on service-orientation for future factory automation solutions and points out what is needed to establish such control architectures in future.

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2 Control Architectures Today

A well-known representation of industrial control architectures is the automation pyramid (Fig. 1). It displays various layers that represent different automation levels. Each layer has its typical automation systems that realize the automation tasks, like PLC, MES, or ERP systems. The lowest level contains the field devices that execute the production process and are operated via their input and output channels (I/Os). The layer above, the process control level, contains the control devices that control and monitor the actions of the field devices, wherefore typically programmable logic controllers (PLC) are used. For implementing the control programs the process logic reads the current output signals and sets the input signals of the field devices depending on the ongoing process. The connection between the field devices and the process control devices is realized through field bus systems or old-fashioned wiring by using a wide variety of communication standards.

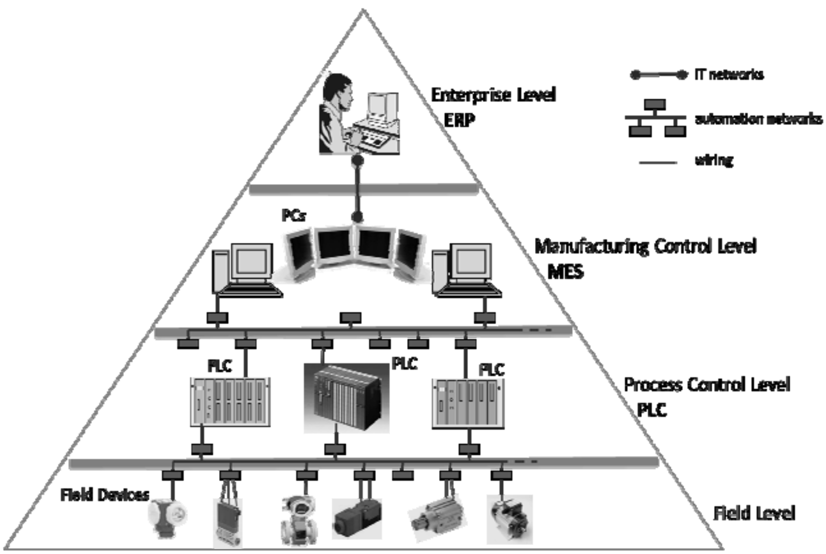

Fig. 1. The pyramid of automation

On the higher layers of the pyramid, the more high-level management and business applications of the production control takes place. Whereas these applications already work with standard IT systems and standards like ordinary PCs, Ethernet, TCP/IP in the lower automation layers special hardware and automation standards are still used. This situation is due to the strict requirements concerning reliability, availability, real-time capability, etc., so that the integration of new IT concepts in lower automation levels is rather restrained.

The drawback of these traditional structures in automation is the overall lack of integration capacity and a high complexity. Since the programming takes place on signal level the control programs are hardware-dependent and complex. For a layer-spanning connection of different automation devices special middleware is needed which is tailored to the respective application. Thus, today's control architectures don't meet the requirements concerning horizontal and vertical integration and an advanced software design and implementation. To cope with these challenges new concepts for industrial automation are required.

3 The Vision of the Automation Network

Nowadays, the biggest drivers for the technical progress are advances in micro electronics and information and communication technology (ICT). Applying new concepts from theses domains to industrial automation can help us to improve our traditional control structures. In the following two concepts are used to develop a new control paradigm for industrial automation; namely Cyber-Physical Systems (CPS) and Service-oriented Architectures (SOA).

In 1991 Mark Weiser described the vision of future computing: "Ubiquitous computing names the third wave in computing, just now beginning. First were mainframes, each shared by lots of people. Now we are in the personal computing era, person and machine staring uneasily at each other across the desktop. Next comes ubiquitous computing, or the age of calm technology, when technology recedes into the background of our lives" [1]. Since then this new paradigm of ubiquitous (or pervasive) computing has more and more become reality. Each of us owns many computers mostly invisible in every day devices like smartphones, cameras, or heart pace makers. The second accompanying revolution can be seen in the communication area. The embedded computers will be even more powerful when they are linked in a network and can exchange information. In the meantime, we even talk of an Internet-of-Things characterized by a situation where each network node is becoming smart. This means that each node can act as an independent addressable computer in a worldwide standardized network. Combining the ideas of ubiquitous computing and the Internet-of-Things will lead us to a new paradigm: Cyber-Physical Systems (CPS). A CPS comprises a network of physically distributed embedded sensors and actuators equipped with computing and communication capabilities [2]. They constitute integrations of computation with physical processes by monitoring and controlling the physical process by embedded computers [3].

Applying this vision to industrial automation structures we will achieve a new control architecture, the automation network (Fig. 2). This vision comprises the automation systems as a CPS so that every device is able to interact with other devices and has some computational power. This enables a strong horizontal and vertical integration within automation systems. For realizing such an automation network, the question arises how the communication is realized with high interoperability and how the tasks can be organized in a transparent, hardware-independent, and flexible way. To avoid the problems due to the signal-based communication we have to move to more abstract descriptions of control processes. Then hardware and software can be linked at a later stage so that processes within the complete life cycle from planning to design, operation, and maintenance can be realized more dynamically and with lower effort. Furthermore, abstract component and task models can improve the interoperability between communication partners so that the basis for high horizontal and vertical integration is provided [4].

A concept that enables such a higher degree of abstraction by encapsulating reusable functions in an open and standardized way is the paradigm of Service-oriented Architectures (SOA).

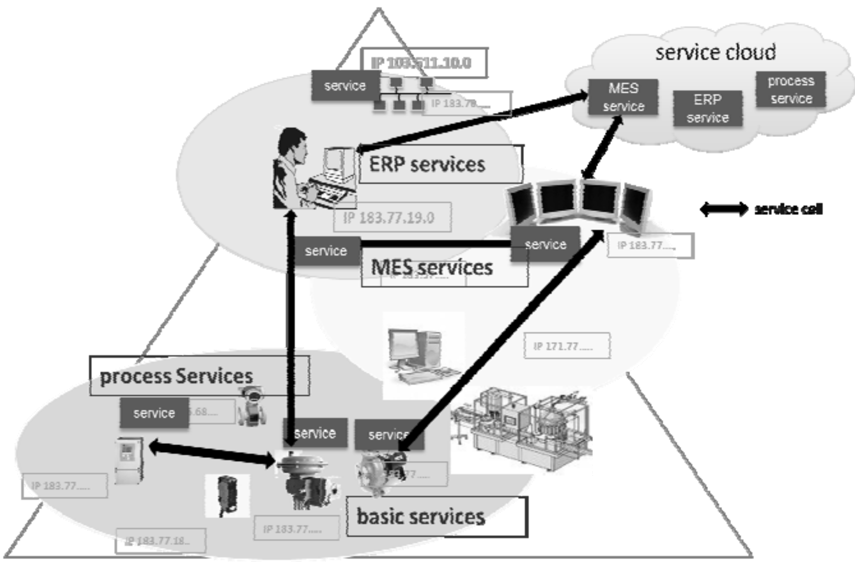

Fig. 2. The vision of the automation network based on SOA and CPS

4 Service-Oriented Automation

Applying the paradigm of service-oriented architectures to industrial automation is a promising approach to decrease significantly the integration and programming efforts within automated production systems. Therefore, we developed the approach SOA-AT to describe the application of service-orientation in the context of industrial automation. Service-oriented architectures have been used for IT applications for a while, particularly in the field of business processes. However, SOA itself is defined as a general concept for software architectures that represents versatile, different methods and applications as reusable and openly accessible services for enabling a platform and implementation independent usage [5]. These services have a standardized and openly accessible interface, whereby the implementation of the functionality is hidden. Thus, SOA is technology independent, high-level concept that provides architectural blueprints [6].

In terms of industrial control we will receive a SOA-AT when all automation functions within the automation network are encapsulated as services. Therefore, the mechatronic functions on field level that execute and monitor the production process are represented as basic services. They constitute the link between the physical and computational processes within the automated production facility. For implementing higher automation functions like control programs, theses basic services can be aggregated to composed services [7]. The process logic for building the high-level functions of the composed services by using other existing services is called service orchestration. The foundation for orchestrating services is the abstract description and representation of mechatronic and computational functionality, and the process logic. This abstraction offers the possibility that automation processes can be planned independently of the production equipment so that the hardware can be selected and assigned at later stages of the planning process. Thus, dependencies during the planning phase can be reduced so that planning processes can be parallelized and the complexity of planning and implementation processes can be reduces [8].

Altogether, our vision of the automation network based on the concept of SOA-AT ensures a holistic automation architecture with far-reaching positive effects on the whole life cycle of automated production facilities.

5 A Roadmap for Service-Oriented Automation Systems

The benefits that could be leveraged by applying service-orientation to industrial automation have been presented. The question arises how such advanced automation systems can be realized based on the current state of the art. We need a suitable migration path to realize the technological and organizational change in industrial automation. In the following we will discuss the most important issues that have to be considered on the way to a service-oriented automation network and some first methods of resolution will be proposed.

5.1 SOA Technology

Regarding the aspect of horizontal and vertical integration the used SOA technology plays a major role. This applies to the requirements on the service specification, the supporting service methods, and on the properties of the communication protocols. To specify a service it has to be decided whether a service should be part of a group of services, like the operations within a web service, which parameters, address, input and output messages, etc., the service has. Additionally, the service technology can comprise special supporting methods of a service, for example a discovery function or the subscription of events. Furthermore, the communication protocol that exchanges the data between service client and provider has to be specified.

Today, the most widely used SOA technology is the web service standard. However, web services were developed for IT applications, so they don't meet the special requirements we have in the automation domain. In the last years, other SOA technologies with the focus on realizing services for technical devices emerged, notably OPC-UA and the device profile for web services (DPWS) [9, 10]. But today, mature, freely accessible, and plain development tools are still missing so that we need further developments concerning tool support.

5.2 Cyber-Physical Automation Systems

Since the capability to provide services isn't supported by field devices today, the idea of CPS supports the realization of a field device bringing its own service functionality. Therefore, current research concerning CPS has to be continued so that each field device could contain an embedded device with the respective service technology implemented for an acceptable price. Furthermore, vendors of automation devices have to equip their products with such embedded devices with service functionality directly.

Of course, this development won't take place promptly but it can be realized step by step. A medium-term solution would be to do the service encapsulation of non SOA-ready devices on a higher computational level so that the device itself hasn't to be changed. However, the far-reaching benefits cannot be achieved until a cyber-physical automation system can be realized so that physical changes to the production equipment can be done easily.

5.3 Process Implementation and Execution

Applying service-orientation to the automation domain enables completely new possibilities for implementing and executing processes. Today, the PLC standard IEC 61131 defines the prevailing way for representing processes that most devices on control level are working with. Since it doesn't support any kind of service orchestration or high-level programming, we need new methods and technologies. However, to create a continuous development, we shouldn't exclude the PLC standards completely, because they are extremely established and accepted. In a first step the standard could be enhanced for using services and generating service orchestrations.

Since ordinary SOA applications comprising pure software systems differ in many ways from automation processes, we have to deal with additional constrains and dependencies when it comes to the execution of a physical process [7]. In particular, services representing mechatronic functionality are heavily dependent on the location of the service and the mechatronic design of the hardware. Thus, we need additional information about the physical structure of the plant and the hardware itself for developing service orchestrations. A characteristic principle of SOA that enables a high degree of flexibility is late binding. This means that the respective service is dynamically chosen and assigned within the service orchestration during runtime. However, high requirements on reliability, repeatability, and predictability have to be considered so that we need also information about the time performance and failure probability of the services. As a start, the ability of late binding could be limited so that we assign the services during the last planning steps before implementation. This makes it much simpler and current engineering processes can be already improved by planning in a hardware-independent way.

5.4 Engineering Concepts

In the last sections, we discussed mainly implementation issues for realizing service-oriented control architectures. However, the far-reaching benefits of SOA based on the higher abstraction degree have to be achieved with the help of suitable engineering concepts and methods. Today, planning processes are too sequential, too comprehensive in content, too much hardware-oriented, and too product-specific [4].

Additionally, the complexity of planning processes grows more and more with the rising complexity of the production facilities.

By means of encapsulating the functionality of automation components in a more abstract way, the gap between planning and implementation phases can be closed, so that seamless engineering processes can be realized. Additionally, the degree of dependence between different engineering domains can be lowered and concurrently, the complexity of planning processes can be handled in more sophisticated way. For setting up or reconfigure automation systems, this affects not only the process control but also other supporting applications, like maintenance, human-machine interaction, monitoring, and diagnosis. Therefore, we need new engineering methods for planning and implementing automation systems that make use of the advantages provided by the paradigm of service-orientation.

5.5 Standardization and Service Definitions

To enable the full degree of flexibility and interoperability a vendor- and customer-comprehensive way to describe and use services is needed. This comprises a standardized service technology that defines how the services communicate with each other and the way the service interface is structured and described. Concerning W3C web services the use of HTTP and SOAP for the communication and WSDL for the interface representation is defined. The much tougher question is how the services themselves are defined in a standardized way so that the services become vendor-independent. Therefore, we would need an overall standard that specifies how automation functionality has to be encapsulated to services and how the services have to be named. However, establishing such an overall standard seems to be quite unrealistic.

A much more sophisticated approach constitutes the semantic description of services [11]. Since the broadly use of semantic technologies may be realistic in the long term but not in the next years, we need a temporary solution. For introducing the use of service-orientation company-wide automation standards constitute a good foundation for at least company-wide standardization of services.

6 Conclusion and Outlook

To accomplish the growing demands on manufacturing systems new concepts for industrial automation are needed. By applying the paradigms of Cyber-Physical Systems and Service-oriented Architectures we can develop agile automation architectures that meet the requirements we have to cope with in future. In order to gain the potential benefits, we have to develop a multi-dimensional approach that comprises a wide range of influencing research topics. Besides the described topics concerning technological issues, planning concepts, and implementation methods there are many more aspects that have to be considered like safety and security aspects, educational and organizational matters, and acceptance problems. Since these changes can't be realized overnight, a suitable migration path and integration methods can help us to do changes in gradual way.

In future, we will continue our work concerning the SOA-AT framework where we focus the development of engineering processes for designing and implementing service-oriented control software. For evaluating the practical suitability of our concepts we will keep on with setting up real demonstration scenarios in the SmartFactory^{KL}. There we have already built a first demonstration system running with a service-oriented control architecture [12] that will constitute the foundation for further applications.

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