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Cyber-physical systems alter automation architectures

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ABSTRACT

Recent automation systems are well structured according to tasks fulfilled by the functions executed on dedicated devices. These functional assignments are also reasons for the design and topology of fieldbus communication systems. New approaches like Cyber Physical System (CPS) require different approaches according to existing communication technologies and engineering. On one side the interaction models advance, and on the other side the demands for industrial plants become a lot more flexible. This article shows upcoming demands on automation systems and discusses new strategies for software deployment of automation applications and communication systems to fulfill these requirements. This includes handling of different types of functional coupling, e.g. loose coupling with internet/web based technologies for interaction and information management. In addition the current device models offering specific device functions have to be adapted to the new CPS approach.

1. Introduction

Todays fast innovation in products leads to challenges in engineering, plant construction as well as automation and control design. In the context of this paper the term *control* is used to describe the engineering, tools, algorithms and communication involved in the signal flow from the sensors to the calculation of set-points of the actuators to affect the production process. For this, many different devices of the production system have to collaborate well. At shop floor, more and more internet connected devices are being used. This trend started several years ago by integrating web servers for Hyper Text Markup Language (HTML) access at Programmable Logic Controller (PLC). After this, other easy to handle internet based protocols, such as File Transfer Protocol (FTP) FTP were used for simpler firmware download. For such fields of application, traditional internet based devices and applications behave the same as embedded devices used in automation at process control level. The upper part of Fig. 1 show the different levels of the traditional plant hierarchy as it is defined in ANSI/ISA 65 (2010) or IEC (2007a). The interactions between tools and devices of different levels are established by means of various communication protocols: vertical data integration, e.g. OLE for Process Control (OPC) or OPC Unified Architecture (OPC UA) Mahnke, Leitner, and Damm (2009), communication between Manufacturing Execution System (MES) and process control level (with PLC and Supervisory Control and Data Acquisition (SCADA)) or fieldbuses down to field level. In traditional automation systems gateways and static defined communication relationships have to be engineered across the layers in particular. The implicit benefit of this is a high degree of ownership and knowledge about the established communication relations.

Moreover different programming paradigms of software components are used for the specific tasks on different hierarchies, only a very small coupling of components across the levels is possible. In fact it is reduced to the exchange of simple data points. This is very generic and efficient, however not flexible. Furthermore, the devices at the two lower levels often use proprietary firmware, based on relative simple or no operating systems. At field level, the functionality of the devices is fixed and may be parameterised to the process demands. Often this functionality is standardized by so called profiles, e.g. PROFIBUS-PA PNO (2010) or PROFIdrive PNO (2006). At process control level – the heart of flexible industrial automation – PLCs are programmed mainly by standardized languages compliant to IEC 61131-3 IEC (2003). Also at MES level, proprietary tools are used. Only the communication between the tools is quasi standardized. However the end user would prefer to have open and deeply interoperable systems up to Enterprise Resource Planning (ERP) level. This requirement is addressed by the CPS approach. Broy Broy (2010) points out that CPS force the collaboration between software intensive embedded devices by using global digital networks. Also Eidson, Lee, Matic, Seshia, and Zou (2012) and Lee and Seshia (2011) point out that CPS are often used in the embedded area as a

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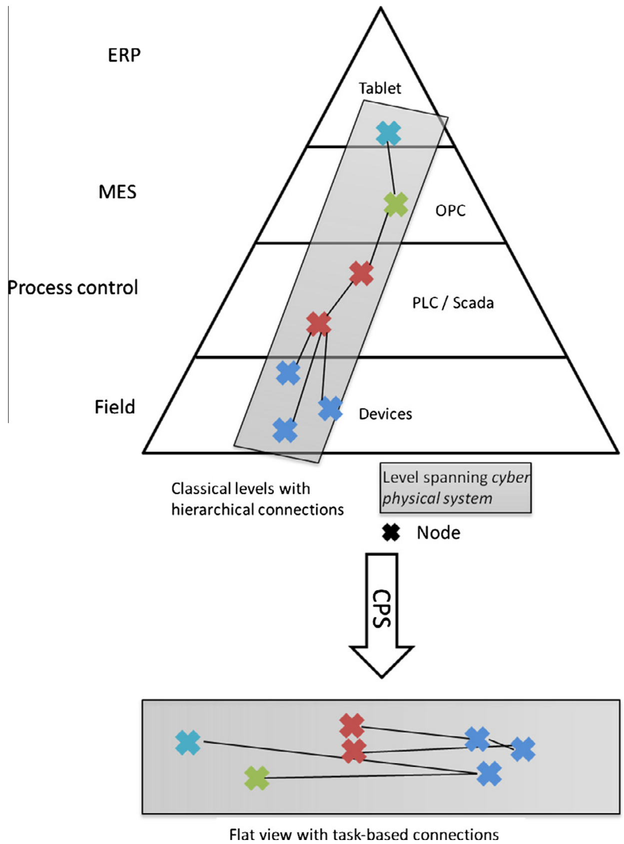

Fig. 1. Evolution of industrial communication from a traditional hierarchy model to a flat network.

combination of software and physical process. Therefore specific considerations are necessary, e.g. for timing constraints, synchronization, etc.

These considerations concern the integration tasks of the (automation) devices in relation to the life cycle of the whole automation system. Fig. 2 shows a cross-section of integration tasks to do in the life cycle. These tasks have got several specific requirements and constraints. Normally integration tasks are based on standards. Thus as well as a common understanding and compatible, interoperable interfaces may be defined. For demonstrating the diversity of relevant aspects standards are considered. A representative application area is the Process Industry, but it is also used in manufacturing. Cross-cutting issues like Security and Safety have to be handled intrinsically and are not discussed in detail here.

A radical variant of the usage of automation devices as CPS is sketched in the beginning of this section. Here all devices are coupled in one physical network and have the opportunity to communicate with each other. In fact, recent Ethernet based communication systems like PROFINET support network topologies, where each device is integrated in one physical network without stopover. Special network components have to take care about different datagram types, e.g. IP traffic is forwarded but real time datagrams are handled locally only. These components are required to operate on ISO/OSI layer-3, where IP is defined. Switches that offer services on this layer are called managed-switches and include router resp. gateway functionality.

At the moment there are some restrictions to integrate a complete IP communication stack in each sensor or actor. There are commercial reasons and of course also practical concerns. For instance, security aspects are not considered in recently implemented device models. Also the hiding of the know-how of manufactures and plant operators have to be guaranteed. Especially determinism and timing constraints in automation area have to be fulfilled in new communication approaches. These requirements are important inhibition thresholds for the introduction of new concepts in automation area. On the other side, automation is also in alteration. Examples are the introduction of de-central periphery of the usage of Ethernet based communication systems. Thus, many experts prefer a well defined migration strategy. This strategy implies, that existing network topologies will be reused and new communication demands will be weaved in at specific access points. So the closed coupled control loop is untouched and the new features can also be satisfied. Such a system is shown in Fig. 3. First discussions on this subject were lead in Riedl, Zipper, Meier, and Diedrich (2013).

The benefit of the CPS approach can also be seen at the smooth integration at runtime between software components of different levels. Therefore it is important to establish the communication relation in the background, without additional configuration

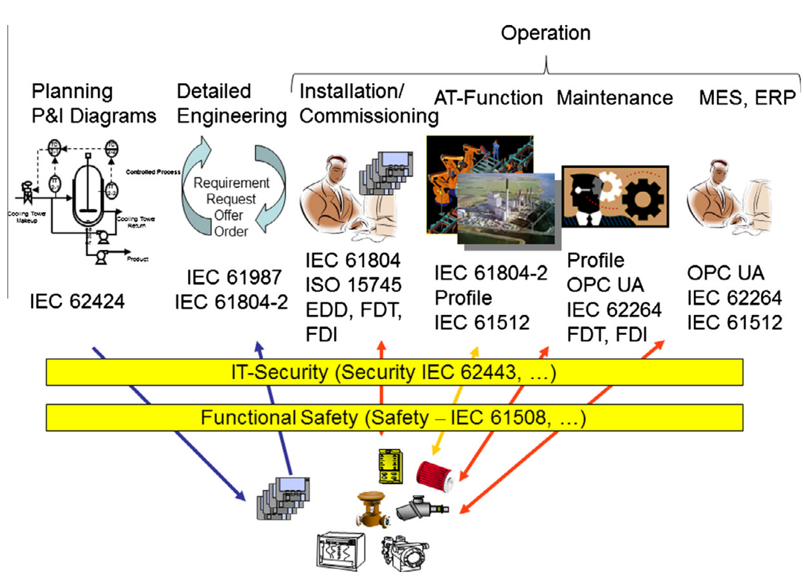

Fig. 2. Different aspects of device integration.