



A survey of “Industrie 4.0” in the field of Fluid Power – challenges and opportunities by the example of field device integration

Raphael Alt *, Hubertus Murrenhoff * and Katharina Schmitz *

RWTH Aachen University, Institute for Fluid Power Drives and Systems (IFAS),
Campus-Boulevard 30, D-52074 Aachen, Germany*
E-Mail: Raphael.Alt@ifas.rwth-aachen.de

This contribution gives a brief introduction to general aspects of “Industrie 4.0”. Besides basic strategies to improve the added value and flexibility of a production, challenges of the transformation, which have to be overcome by the companies, are shown. The commissioning of production machines gains more significance in a dynamic production of a smart factory, so that in consequence the automation of the commissioning would bring significant advantages. Current fluid power systems are not excluded, since most steps of the commissioning are still done manually by the technician. By analysing the integration of a linear electro-hydraulic actuator into a production machine, limitations and problems of current systems are identified and related to the field of fluid power. The analysis of possible solutions is leading to methods and modern information and communication technology, introduced by the “Industrie 4.0”.

Keywords: Cyber-physical system, intelligent field device, plug and produce, plug and play, commissioning, Industrie 4.0, Industrial Internet of Things, electro-hydraulic actuator

Target audience: Fluid Power, Automation, Production

1 Introduction of the Industrial Internet of Things (IIoT)

1.1 Motivation

The Internet of Things (IoT) is affecting everyone. It describes the fusion of computational power (embedded systems), mechatronic systems and their interconnection via internet. Various industrial branches are influenced, reaching from the energy sector (smart grids) over the field of consumer products (smart home, smart phone, etc.) to the manufacturing industry. Within this branch, the “Industrial Internet of Things” (IIoT) or “Industrie 4.0” (German) was firstly introduced as part of the German high-tech strategy in 2011 at Hannovermesse with its goal to master upcoming challenges and to meet new requirements in times of market globalization /1/.

The greater number of competitors, the demand of cheap, individualised goods and the shorter time-to-market sets up new requirements to the manufacturing industry in terms of flexibility, dynamics and adaptability besides the classical ones such as a high quality and low costs.

In order to achieve the ambitious and partly classically contradictory goals, the German organisation “Plattform 4.0” outlined a roadmap to deploy the Industrial Internet within the next 10 to 20 years. Based on the first three industrial revolutions, shown in figure 1, mechanisation, electrification and automation by computational power, the enabling technologies of the fourth industrial revolution are all related to the field of Information and Communication Technology (ICT) such as Net Communication, Data Analysis, Microelectronic, Safety & Security and Semantic Communication /2/.

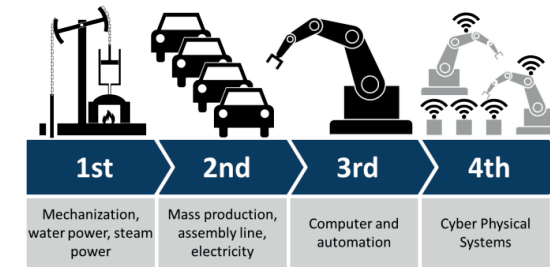


Figure 1: Industrial revolutions /3/

1.2 Basic Concepts

Key concept of “Industrie 4.0” is to make relevant information available in real-time by linking all participating instances of the whole production process and to derive the ideal value-added flow for any step of the production at any time /4/.

Current strategies for implementing IIoT in the manufacturing industry are focusing on four dimensions as shown in figure 2 /5/.

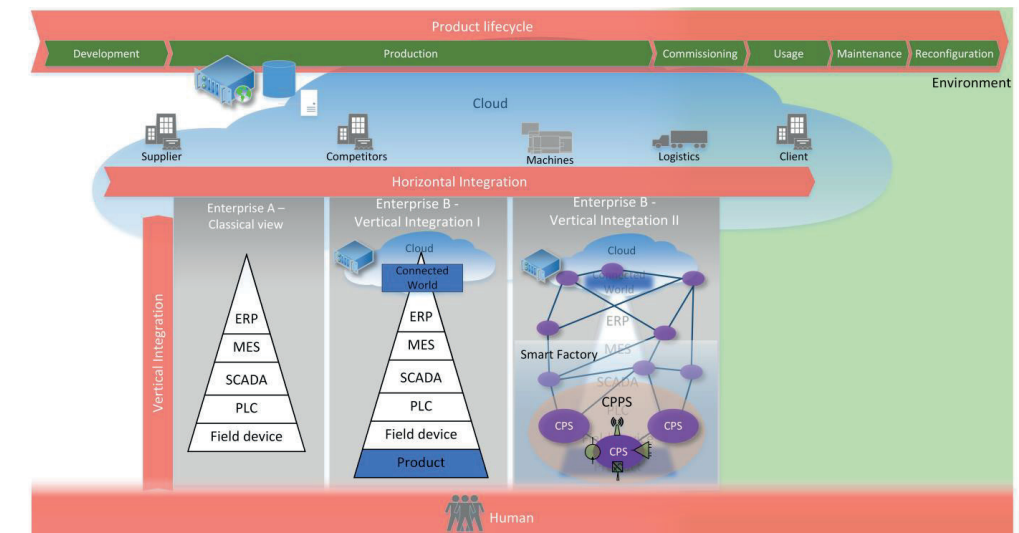


Figure 2: Four dimensions of “Industrie 4.0” in the industrial environment (referring to /5/)

By **Vertical Integration**, components and IT-Systems of different hierarchy levels are linked together. The classical hierarchy of the automation system pyramid, reaching from the field device to the enterprise systems, gets reduced through a decentralised production network composed of intelligent production units, so called cyber-physical systems (CPS). As the product is choosing its own path through the cyber-physical production system (CPPS), it can be added to the automation system pyramid. “Connected World” is representing outside connections via the internet. /6/

Horizontal Integration addresses the interconnection of all participants across the value-added chain of the production process and creating value adding networks, for example different production machines in the enterprise, as well as participants outside the enterprise. In this field, many digital business models are arising.

/6/

Integrated Engineering describes a digital consistency of information across the whole **product lifecycle**. Relevant information is recorded and transferred continuously to be able to retrace every step of the tool chain within the different phases of engineering and production. /6/

The **human** role in the professional environment changes from being deeply integrated into the production process to higher planning and guiding tasks due to more intelligent production and personalised assistance systems. Fast changing environments and systems require high flexibility and continuous readiness to learn. Technicians specialised on a single domain are becoming systems engineers. /6/

Although current developments differ in many aspects, they all match in significant increasing internal system complexity. Tasks of the intelligent production systems will be handling this complexity and making essential functions much easier to use for operators, clients and everybody interacting with the systems.

1.3 Economic Benefits

The economic benefits of the fourth industrial revolution are predicted to affect the whole value-added chain of a new product from the development, to manufacturing process, up to its usage and reconfiguration. New profitable and highly scalable business models, strongly based on using and sharing real-time data and information are currently arising /4/. The promised benefits for the manufacturing industry are represented by Wieselhuber as following /7/:

- higher efficiency of production (quality, output, availability)
- higher effectivity of production (flexibility, changeability, adaptability)
- reduced capital costs for production goods (XaaS - Everything as a Service)

WGP estimates a reduction of costs of up to 70% in parts of the production /4/.

1.4 General challenges

Although the predicted benefits are very promising, a few people in the field of Fluid Power seems to know exactly how to deal with the changing circumstances resulting in new requirements imposed to their future products and enabling new potential digital business models. Studies show that especially small and medium-sized enterprises, four out of ten are not following any implementation strategies or taking part in the development and application of IIoT-technologies /8/. One explanation can be found in very diverse understandings of “Industrie 4.0” due to the confusing promotions by the media and marketing divisions, which are labeling anything “IIoT ready”, legitimate or not. Other challenges are seen in high investments /4/ to compensate the lack of technical expertise and infrastructure /4/ on the one hand and to quantify the resulting benefits on the other hand. As well as concerns about Cyber Security /4/, another problem in the classical field of mechanical engineering is the understanding of the correlation between abstractly discussed digital business models and thus necessary design modifications to the components and machines in a company. Condition Monitoring (CM) and Predictive Maintenance (PdM) are broadly recognised future applications and accepted business models related to the Industrial Internet, but for many parties they are the only ones.

2 Commissioning of a linear electro hydraulic actuator

To examine another point of view to the current technologies of “Industrie 4.0” and to relate them to the field of fluid power systems, the following part presents the conducted analysis of the commissioning of an electro-hydraulic-actuator (EHA) which could be integrated by the Original Equipment Manufacturer (OEM) into a machine. As depicted in this section, a majority of the commissioning process is still done manually. Within the settings of a smart factory, plug and play or plug and produce usually combines the installation and commissioning of a system. As part of plug and produce, the goal is to facilitate, speed up and maximise automation of the integration process of a new system for production.

2.1 Commissioning state of the art

2.1.1 Definition

Goal of the commissioning process is to set up the functionality and prove its performance to fit its design requirements. To do so, different tasks need to be done (referring to /9/):

- Setting up and checking the functionality of single components and their interacting behaviour
- Adjusting and optimising parameters
- Eliminating failures and mistakes
- Completion of the documentation

2.1.2 Structure and connections

Figure 3 shows the EHA built into a machine and other interacting systems. The vertical hierarchy of the automation pyramid and the differences in communication can be stated as following. The hydraulic system is composed of a proportional valve, pressure sensors, a cylinder, a position sensor and hoses, all connected to a simplified constant pressure source. The valve is linked to a valve controller and an axis motion controller. Signals in this presented hierarchy level of the field devices are mainly transmitted analogue. Without the correct settings, those transmitted voltages and currents do not represent usable information. The programmable logic controller (PLC) is connected via fieldbus. To obtain a safe functionality of the drive, the mentioned connections need to meet real-time communication (RTC) requirements. Higher hierarchy level systems (Enterprise-Resource-Planning (ERP), Manufacturing Execution System (MES), Supervisory Control and Data Acquisition (SCADA)), are connected to the PLC by using the Local Area Network (LAN) and have non-real-time communication (NRT).

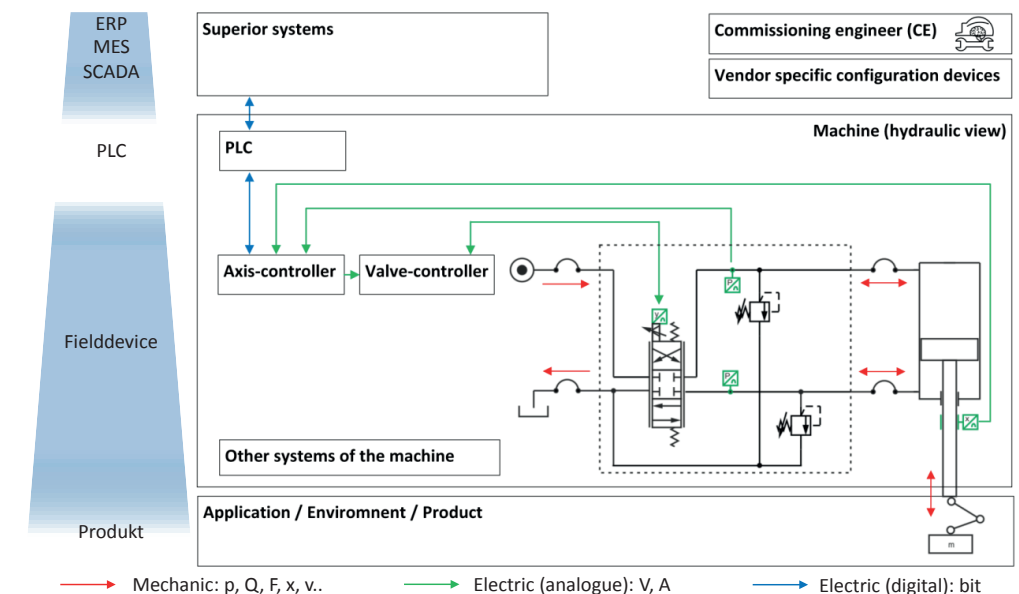


Figure 4: Components and connections of a linear electro-hydraulic actuator

2.1.3 Steps of the Commissioning

After installation, the ramp-up process of the EHA carried out by the OEM can be divided into following phases:

- Validation of the assembly
- Setting up IT-Systems
- Integrating field devices
- Configuring Human-Machine-Interface (HMI)
- Activating the System (Modes: Fail-Safe, Open-Loop, Closed-Loop)
- Testing
- Completion of the documentation

After setting up the system, the commissioning engineer (CE) needs to check the assembly of all hydraulic and electric parts and their connections. Firmware on the PLC as well as on configuration devices needs to be installed or updated. Afterwards, every broadcasting and receiving device needs to be configured to make them understand their communication partner (analogue current and volt or fieldbus). The variety of existing signals and their mapping into higher hierarchy levels makes this step very time consuming and prone to failure in complex systems. The CE uses various data-sheets and his technical knowledge to execute this task. Additional functions for different operating modes, safety and diagnosis are implemented in the PLC. Valve and axis controller are configured and parameterised by plugging-in an additional vendor-specific configuration device. Configuration and mapping of signals for the HMI need to be carried out as well.

To obtain a safe first activation of the drive, the maximum input values of the valve need to be limited, pressure relief valves and the pressure source are set manually to a low level by the CE. In manual or open-loop control mode, tests for the correct direction of the drive and a corresponding position signal are part of the plausibility routine. Checks for mechanical collisions are carried out as well. Dissolved gas is released out of the system, oil gets refilled and the fail-safe system limitations are set back to the desired operating values. As the controller gets activated, parameters are optimised during reference runs in closed-loop control mode. Finally, a test cycle is executed and the results are added to the documentation. The machine is ready to be integrated into the client's production process.

2.2 Analysis of the Use-Case

As described in the section above, most of the commissioning steps are done manually by the CE or the technician. Only in modern systems, a few steps are executed semi-automatically by the support of assistant systems. A detailed analysis of every single step referring to the following criteria has been carried out:

- Involvement of technical domains (mechanics & hydraulics, electronics, information technology)
- Necessary knowledge and information
- Source and transfer of the information
- Type of execution (manual, semi-automatic, automatic)

Several results can be summarised as following.

2.2.1 Involved technical domains and type of execution

To automate a specific task, it needs to be connected to information technology. In the analysed use-case, around three-quarter of the steps of the commissioning are somehow related to information technology (see Figure 5). In many cases, almost every step is directed to the manual action of a commissioning engineer or technician. Only about one quarter of the steps exclude any relation to information technology.

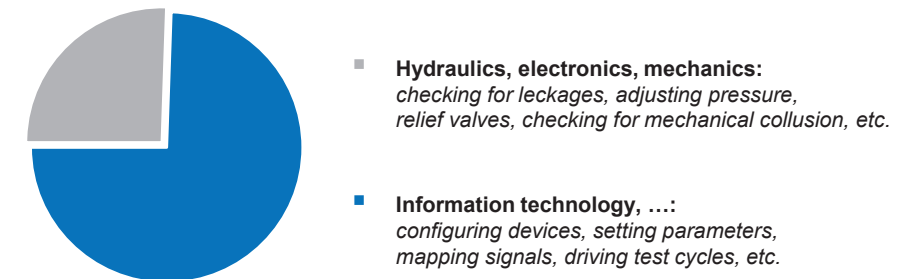


Figure 5: Involved technical domains by the analysed commissioning steps

2.2.2 Necessary knowledge

Much knowledge is applied and a lot of information is needed during the commissioning process. The model pyramid of knowledge ("Wissenspyramide") of Fuchs-Kittowski /10/, describes the creation of knowledge by linking different information together. Figure 6 gives an example of required information and knowledge for the commissioning process. Classically, knowledge is mostly created by the commissioning engineer to derive and execute correct actions.

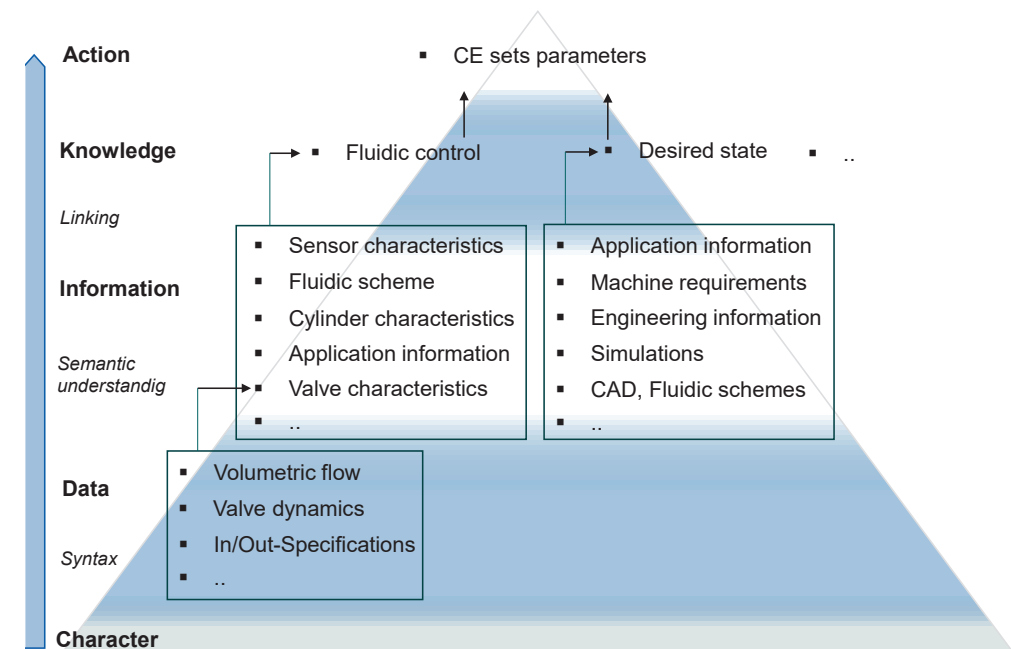


Figure 6: Exemplary necessary knowledge and information for the commissioning (according to /10/)

2.2.3 Source and format of information

Information has no specific structure. It can be represented in lists, diagrams, tables, free text, figures, data bases and many more. In practice, a large amount of information is transferred analogue, via sheets of paper (e.g. manuals, valve diagrams, catalogues, etc.) or during conversations for example between the commissioning technician and the development engineer of the machine. Even the format of information of digital sources is

various, too. Information is stored in configuration files, digital datasheets, simulation models or simple pdf-files, which can be downloaded from the manufacturer's homepage.

2.3 Evaluation of the Use-Case

The various relations of commissioning steps to information technology shown in figure 4 are representing third industrial revolution technology (automation through computational power) in fluidic production machines. At the same time, the conducted use-case analysis illustrates limitations of "Industrie 3.0" referring to the automation of individual tasks. Figure 7 lists those challenges and relates them to possible technological solutions of "Industrie 4.0" to solve the problems by automating individual tasks as well, represented by the automated commissioning.

I. 3.0 Lack of knowledge	I. 4.0 Modern ICT
<ul style="list-style-type: none"> incompatible communication unstructured data information temporally and locally distributed missing coherences systems have no experiences 	<ul style="list-style-type: none"> semantical and standardized communication between random participants consistency and linkage of information „real-time“ information Machine Learning, Big Data
Unflexible action	Cyber-physical systems
<ul style="list-style-type: none"> actuators without embedded IT-systems manual tasks done by technical staff 	<ul style="list-style-type: none"> horizontal value network (SoA) smart components, digital functionality
General problems of the commissioning	General solutions for the commissioning
<ul style="list-style-type: none"> individuality ≠ profitability ≠ flexibility labour-intensive at individual tasks 	<ul style="list-style-type: none"> commissioning mostly automatic self-organizing & convertible modules staff acts as troubleshooter, supported by assistance systems

Figure 7: Challenges of "Industrie 3.0"-systems and technological solutions of "Industrie 4.0" by the example of commissioning

2.3.1 Knowledge

One major problem is the insufficient knowledge of the machine. Being caused by multiple reasons, one is the incompatibility of the various communication paths between systems of different hierarchy levels, different functionality or different manufacturers as described in the section above. To achieve a good interoperability, basic standardised communications for the manufacturing industry like for example OPC-UA and AutomationML are introduced /11/.

Unstructured and undefined information, i.e. a mix of numbers, diagrams and drawings on a datasheet, cause problems in terms of machine based processing and effective usage of information. Today, humans interpret the variety of data and input individual required values into the machine. As consequence experts in multiple working groups among different branches are defining basic attributes in order to describe useful properties and features of components and whole systems to increase its computational processability with minimum effort. Current interim results are continuously being integrated in eCI@ss Standard /12/.

Access to information is limited by its local and temporal range which is defined by the source of information. For example, information that was created during the phase of engineering can provide added value two years later for the ramp-up process of machines in another country. Cloud-technology enables worldwide availability of information by connecting via internet for an unlimited period of time. In other local approaches, useful information, which is generated along the whole product lifecycle, gets stored on the product or a virtual data space directly linked to the product. Current generated information can also be sent to other places in real-time.

Currently, technical, organisational and structural knowledge concerning the commissioning is largely based on human experience and provided by specialised technicians and engineers. In order to handle correlations and dependencies, data models of different perspectives are built up and combined in Virtual-Machine-Models (VMM) /13/. The digital twin is one among others discussed. It describes a virtual representation of the real machine which can be analysed in terms of actions and reactions. Additionally, analysing collected data of many commissioning processes (Big Data) and applying machine learning algorithms can build up information technological machine experience and thus improve future ramp-ups.

2.3.2 Action

Based on the latest knowledge, different actions are conducted. Bigger tasks, like the automation of commissioning, are divided into small tasks, solved by functions and services, provided by the available smart components in the system. This can be achieved by a service-oriented architecture (SoA) which had been initially applied in the field of distributed IT-Systems /13/. Referring to the "Industrie 4.0" the service oriented architecture is based on CPS which are the enabling elements to increase the interoperability of systems. They provide encapsulated services and functions that can be executed independently of each other. The flexible arrangement of independent services makes the system adaptable to different configurations and other changing constraints. Automated tuning of the integrated axis controller would be a service in the commissioning process, offered by a smart valve. In several branches, typical descriptions, operational modes and functions of machines are currently being standardized via the OPC-UA Companion Specifications. "AverageCycleTime" and "MachineCycleCounter" for example, represent supplier and machine independent functions, defined in EUROMAP 77 /14/ and EUROMAP 83 /15/ by the branch of Plastic and Rubber Machinery to increase the interoperability of injection moulding machines.

To communicate available services and relevant information right after connecting the devices to the system, a basic communication is another obligatory feature of a CPS.

Several steps of the commissioning might still be executed manually by the technician. Those steps rely on elements that cannot be manipulated via information and communication technology (ICT) since they are not integrated into the system, some not even electrified. Besides adding on-board electronics (OBE) to passive elements, other smart components in the system might provide the required functionality. For example a cylinder does not need to be connected necessarily to the IT-system, if the attached valve provides additional functionality.

2.3.3 General aspects

The classical commissioning process is very reliant on the performing commissioning engineer or technician. Knowledge and manual actions are related directly to this person and thus they are very limited regarding their local and temporal availability. Skills of a single person are not scalable compared to software and furthermore a technician can leave the company with its valuable knowledge and experiences. Different abilities of humans and non-transparent ramp-ups cause unpredicted results in quality, duration and costs of the process which makes it hard for a company to calculate without risking production delays or having resources overhead.

In the scenario of a smart factory, commissioning is becoming very important. The highly flexible production and the reduction of capital costs by temporary renting a production machine (Pay-per-Use) is causing plenty of reconfigurations and repeated commissioning of the machines.

Consequently, mostly automated commissioning (Plug-and-Produce) is the desirable method in a smart factory. People in the production are helping out when the machines action is limited or unexpected errors occur. Modern assistant systems with a personalised human-machine-interface based on visual guidance technology, like augmented reality is supporting non-specialised personal in different execution tasks. If expertise is required, engineers or specialised technicians can support via remote assistant systems.

3 Summary and Outlook

This paper describes basic limitations of the automated integration of current fluid power field devices by the example of a linear electro-hydraulic actuator. As a result of the technological achievements of the third industrial revolution, many commissioning steps and components are already related somehow to information technology. Still, most steps during the commissioning are conducted manually by a commissioning engineer. This can be explained by the individual and changing character of specific tasks, such as a commissioning, that is not feasible for classical automation technology. Due to continuously changing circumstances, knowledge and experience is required to conduct the correct actions.

Developments of “Industrie 4.0” are tackling this problem. On the one hand basic definitions of functions and standardisation of information are improving the computational understanding and interoperability of individual machines. On the other hand, the availability of data and information is improved massively by modern information and communication technology, for example via global accessible clouds. Data is collected consistently across the whole product lifecycle. Through powerful algorithms and increasing computational power, knowledge is generated via big data analysis and machine learning.

Increasing the flexibility of actions and improving the interoperability of different systems can be achieved by the service-oriented architecture. It makes it possible to processes bigger tasks, like the automation of commissioning, by executing distributed functions and services, provided by the system. Cyber-physical systems are the basic element due to their embedded intelligence, basic communication and encapsulated services and functions.

Current research is focusing on the vertical integration of field devices in the defined use-case by implementing a service-oriented architecture of cyber-physical systems. Another digital concept like Assed Administration Shell (AAS) /16/ has the potential to enable horizontal integration, to improve vertical integration and to achieve a consistency of data across the whole product lifecycle.

Furthermore, more use-cases can be analysed in a similar way to complete the picture of future requirements to consider services and attributes in current standardisations.

4 Acknowledgements

The survey on the industrial Internet of Things in the field of fluid power is funded by FKM - Forschungsfonds Fluidtechnik. The authors thank all experts who enriched the study with their expertise in the conducted interviews in order to reflect the current state of the art of commissioning in the field of fluid power.

Nomenclature

Abbreviation	Description
AAS	Assed Administration Shell
CE	Commissioning Engineer
CM	Condition Monitoring
CPPS	Cyber-physical production system
CPS	Cyber-physical system
EHA	Electro-Hydraulic Actuator
ERP	Enterprise-Ressource-Planning
HMI	Human-Machine-Interface

ICT	Information and Communication Technology
IIoT	Industrial Internet of Things
IoT	Internet of Things
LAN	Local Area Network
MES	Manufacturing Execution System
NRT	Non-real-time communication
OBE	On-board electronics
OEM	Original Equipment Manufacturer
PdM	Predictive Maintenance
PLC	Programmable logic controller
RTC	Real-time communication
SCADA	Supervisory Control and Data Acquisition
SoA	Service-oriented Architecture
VMM	Virtual-Machine-Model
XaaS	Everything-as-a-Service

References

- /1/ Kagermann, H., et al., *Industrie 4.0: Mit dem Internet der Dinge auf dem Weg zur 4. Industriellen Revolution*, In: VDI Nachrichten, Nr. 13-2011, VDI Verlag GmbH 2011
- /2/ acatec, Arbeitskreis smart service Welt, *SMART SERVICE WELT - Umsetzungsempfehlungen für das Zukunftsprojekt Internetbasierte Dienste für die Wirtschaft*, Abschlussbericht, 2015
- /3/ Wikipedia, *Industrial revolutions and future view*, https://en.wikipedia.org/wiki/Industry_4.0#/media/File:Industry_4.0.png, visited on October 1, 2017
- /4/ Wissenschaftliche Gesellschaft für Produktionstechnik (WGP), *WGP-Standpunkt Industrie 4.0*, 2016
- /5/ VDI/ VDE, *Statusreport - Referenzarchitekturmodell Industrie 4.0 (RAMI4.0)*; 2015
- /6/ BITKOM, VDMA, ZVEI, *Umsetzungsstrategie Industrie 4.0*, 2015
- /7/ Dr. Wieselhuber & Partner GmbH, Fraunhofer IPA, *Geschäftsmodell-Innovation durch Industrie 4.0 Chancen und Risiken für den Maschinen- und Anlagenbau*, 2015
- /8/ Schröder, Christian, *Herausforderungen von Industrie 4.0 für den Mittelstand*, Friedrich-Ebert-Stiftung 2016
- /9/ Wunsch, G., *Methoden für die virtuelle Inbetriebnahme automatisierter Produktionssysteme*, Dissertation Universität München, Herbert Utz Verlag, 2007
- /10/ Fuchs-Kittowski, K., *Wissens-Ko-Produktion – Organisationsinformatik*, Gesellschaft für Wissenschaftsforschung, Berlin, 1. Auflage, 2001

- /11/ Schleipen, M., Lüder, A., Sauer, O., et al., *Requirements and concept for Plug-and-Work*, Automatisierungstechnik, DE Gruyter, Band 63, Heft 10, 2015
- /12/ eCl@ss classification and product description, <http://www.eclasscontent.com/> , visited on October 1, 2017
- /13/ Abel, M., *Automatisierte Inbetriebnahme von rekonfigurierbaren Bearbeitungsmaschinen mit serviceorientierten Paradigmen*, Dissertation Universität Stuttgart, Fraunhofer Verlag, 2017
- /14/ EUROMAP 77, <http://www.euromap.org/euromap77>, visited on October 1, 2017
- /15/ EUROMAP 83, <http://www.euromap.org/euromap83>, visited on October 1, 2017
- /16/ Plattform Industrie 4.0, ZVEI, *Struktur der Verwaltungsschale–Fortentwicklung des Referenzmodells für die Industrie 4.0-Komponenten*, Berlin, 2016