Kortela, Jukka; Nasiri, Babak; Smirnov, Alexander; Lahnalammi, Antton; Jämsä-Jounela, Sirkka Liisa

Educational Setup for Service Oriented Process Automation with 5G Testbed

Published in:
IFAC-PapersOnLine

DOI:
10.1016/j.ifacol.2017.12.023

Published: 01/12/2017

Document Version
Publisher's PDF, also known as Version of record

Available online at www.sciencedirect.com

ScienceDirect

IFAC PapersOnLine 50-2 (2017) 127–132

Educational Setup for Service Oriented Process Automation with 5G Testbed

Jukka Kortela * Babak Nasiri * Alexander Smirnov * Antton Lahnalammi * Sirkka-Liisa Jämsä-Jounela *

* *Aalto University, Espoo, 00076 Finland (e-mail: name.surname@aalto.fi).*

Abstract: There is a constant challenge in process industry to reduce costs because of tight competition on the global market. On the other hand the advancement in the new technologies such as Open Platform Communications Unified Architecture (OPC UA), Industrial Ethernet, 5G, and cloud computing provide the possibility to implement cost effective Cyber-physical systems (CPS). This allows flexible, reconfigurable, scalable, interoperable business models. These trends in the process industry should be taken into account while teaching future engineers. In this article the modern process automation setup which includes three miniplants with optional 5G connectivity is described along with teaching approach for executing the students projects. Using this infrastructure students obtain knowledge with emerging industrial technology and become the actors of upcoming industrial revolution.

Keywords: Educational setup, Industrial Ethernet, cloud computing, 5G, industrial revolution, teaching, OPC UA

1. INTRODUCTION

Global competition increases the pressure on the process industry to reduce the costs and at the same time the technological trends such as OPC UA, Industrial Ethernet, 5G and cloud computing provide an opportunity to make the processes more effective. Advances in communication and computing devices have enabled a new generation of low cost, high performance electronic components, increasing communication capabilities and processing power. Particular emphasis has been put on platform independence, security, and scalability of solutions. These advances are associated with the 4th industrial revolution (Industrie 4.0) (Kagermann et al., 2013), where physical devices (Internet of Things, IoT) (Hellinger and Seeger, 2011) are connected together to form Cyber-Physical Systems (Lee and Seshia, 2017; ITU; Mäntylä, 2016). The broader context of CPS includes Service-Oriented Architectures (SOA) (Boyd et al., 2008) and cloud computing (Badger et al., 2012).

The key role is devoted to the connectivity between the devices (Taleb et al., 2016) which provides accurate data capturing on all levels of the plant. This makes possible to detect inefficiencies and to get additional insight into the process, therefore having the possibility to implement advanced optimization strategies. 5G allows to achieve these goals in a flexible manner, avoiding additional costs and restrictions related to the early planning of the cabling. This results in agile a service-oriented architecture in process automation combined with cloud computing and Web services technologies (Karnouskos and Colombo, 2011). Thus, flexible, reconfigurable, scalable, interoperable network-enabled collaboration between decentralized and distributed cyber-physical systems becomes possible.

To meet the future challenges it is extremely important to train young chemical process engineers to have capabilities to work in this kind of technology driven connectivity environment.

In the literature many interesting and high quality educational setups have been lately reported and discussed. The educational approach for advanced optimization strategies such as model predictive control was presented by Honc et al. (2016); Shariati and Abel (2016). The challenges of process control education with Industrial Ethernet were discussed by Sharma et al. (2016). The education of CPS environment with application to heat, ventilation, and air conditioning was described by Beghi et al. (2016). In this work we will present the service oriented process automation set up which has been built around the three mini pilots.

This article contributes by describing how cloud computing, OPC UA and 5G network are used in the educational setup. The main benefits and features for educational purposes are highlighted with respect to the traditional wired system.

The article is structured as follows, the general system description and its components are presented in Section 2. The case studies with particular physical plants used are discussed in Section 3. Section 4 describes the educational process and its steps. The conclusions are summarized in Section 5.

⋆ We would like to thank our colleagues professor Raimo Kantola, professor Riku Jäntti, Jose Costa-Requena, and Jesus Llorente Santos from the Department of Communications and Networking in Aalto University for the help with 5G system setup.

10.1016/j.ifacol.2017.12.023

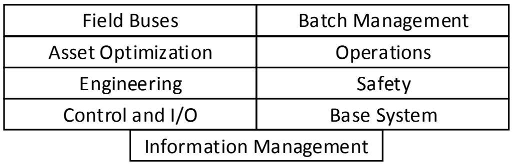

Fig. 1. Functional areas of the System 800xA

2. DESCRIPTION OF THE PROCESS AUTOMATION EDUCATIONAL SETUP

The process automation teaching environment consists of ABB System 800xA DCS with the duplicated main servers, as illustrated in Figure 2. Configuration stations and operator stations are virtualized Windows workstations. They are installed in two highly efficient physical Dell 730xd servers that can be accessed remotely for the training and learning purposes. The same servers include highly scalable Play and Spark frameworks installed on the Linux server that access the main system through the OPC UA client. Finally, the sensors / actuators can be accessed through the real-time ethernet and PLCs (Programmable Logic Controller), or Rasberry Pi I/O Gateway by utilizing the newly installed prototype 5G network.

2.1 Functional areas of the System 800xA

The System 800xA functionality is divided into the Base System and a set of options as shown in Figure 1. Options can be added to the system based on the needs of the process that is controlled.

Integrated Engineering Workspace environment handles the complete lifecycle of the automation project, from configuration, visualization and library management to commissioning. Safety follows IEC 61508 and IEC 61511 compliant Safety Instrumentation System (SIS), spanning from the SIL rated field devices, I/O modules, and controllers to field actuators. Control and I/O consists of standards-based hardware and software with industrial I/O interfaces. Information management system collects, stores, and presents the real-time process, historical and business data. Batch management system handles recipe management, batch and procedural control according to ISA S88.01. Finally, Field Buses / Device Management system integrates intelligent field devices via all major field bus standards.

2.2 Topology of ABB System 800xA

The System 800xA architecture consists of computer and devices that communicate with each other through different types of communication networks.

Servers of the System 800xA The Aspects Objects architecture is the cornerstone of the System 800xA. It provides information-centric navigation a consistent way to instantly access all information without having to know how and by which application the information is handled. For example, a valve is real object, including manufacturers specifications, mechanical drawings, a maintenance schedule and history, ordering information for parts, physical location in the plant, faceplate for operator interface, graphic symbol for display on graphics, etc. An Aspect object presents this data as a menu of choices accessible from the object anywhere it appears in the system.

The OPC Connectivity server provides access to the controllers and other data sources over the network. These include services, such as OPC Data Access, OPC Alarm and Event, OPC Historical Data Access, and System messages. To increase the robustness additional redundancy is added by duplicating the Connectivity server in the system.

The System 800xA supports a full array of historical and reporting functions. The Information Manager system with the database get its data from the Connectivity servers basic historical logs utilizing the OPCs HDA standard protocol. In case the Information Manager machine goes off line for a while, there is no loss of information. The data can be retrieve for the whole time period from the Connectivity Server when it comes back on-line.

The configuration of users and security in a Windows is done from the central location – the domain name server (DNS).

Communication networks of the System 800xA The Control network is a local area network (LAN), optimized for high performance and reliable communication, with predictable response times in real-time. It is used to connect the controllers to the servers.

2.3 OPC UA Wrapper

OPC UA is a widely recognized platform independent interoperability standard for industrial automation. It defines requirements for direct, secure, reliable and seamless exchange of data between systems of various scale, ranging from intelligent sensors to mainframes.

The OPC UA Wrapper provides OPC UA client with access to the System 800xA. The UA Wrapper exposes available parameters of COM OPC servers in the OPC UA servers address space. From that space the OPC UA clients can access and manipulate parameters. Libraries for implementing OPC UA client are available for all major programming languages and hardware platforms.

2.4 PLC programming

The fieldbus interconnects field devices, such as I/O modules, PLCs, and connects them to the system, either via a controller or directly to a server. ABB System 800xA supports several PLC programming languages. Function Block Diagram (FBD), a high-level graphical programming language, describing program organization units (POU) in terms of processing elements and displaying the signal flow between them, similar to the electronic circuit units. Structured Text (ST) consists of function/function block calls, expressions, conditional statements, iterations and more, familiar to C and Java programming languages. The Sequential Function Chart (SFC) allows describing the sequential behaviour of the control program graphically.

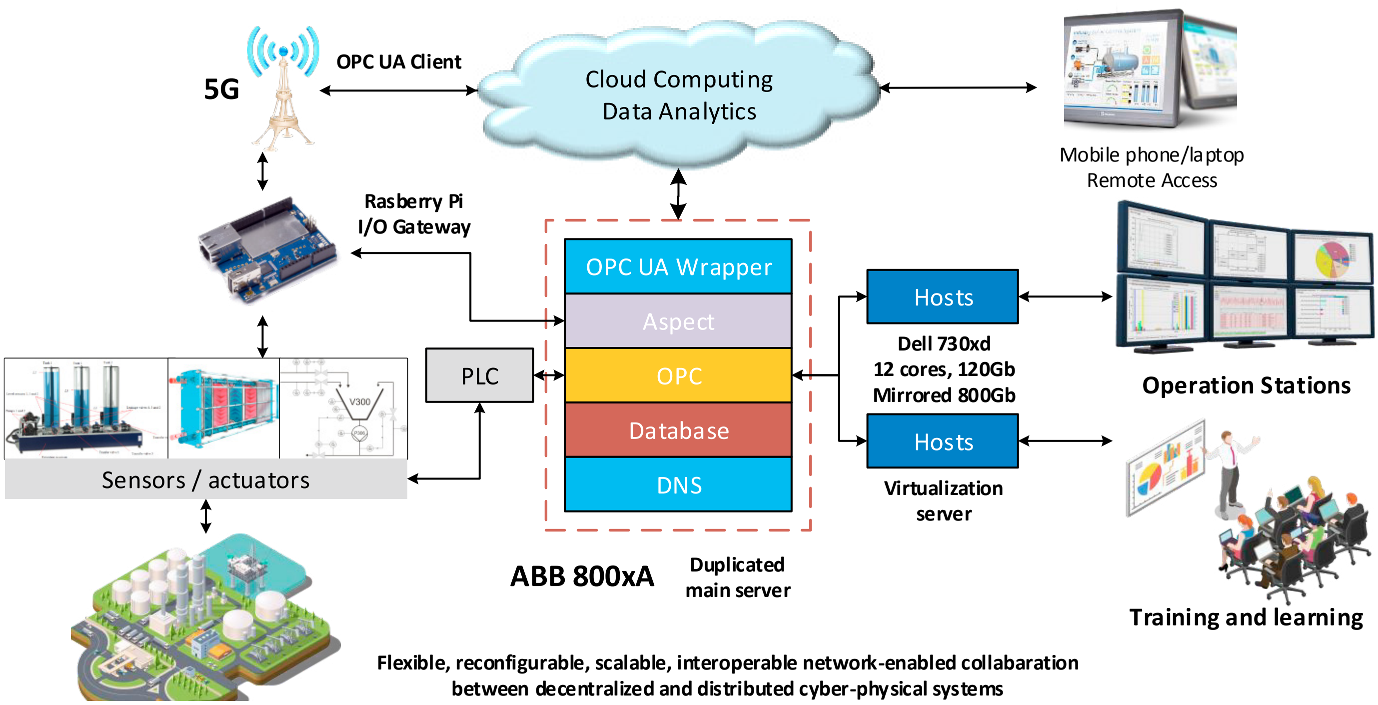

Fig. 2. Factory of the Future. Main components, elements and their interconnection.

2.5 Play Framework

Advanced control and data analytics are executed with Play web framework that has been designed to run Java and Scala programming code. The Play framework uses a fully asynchronous model, and being stateless, it scales predictably in the cloud. The algorithms are coded with Time Series for Spark, enabling an analysis of data sets comprising millions of time series, each with millions of measurements.

Instants DataFrame:s are ideal for traditional machine learning, for example, building a supervised learning model that predicts one variable based on contemporaneous values of the others.

In the TimeSeriesRDD model, lagged time series from the original collection of time series are computed by only looking at a single record in the input RDD. Similarly, with inputting missing values based on the surrounding values, or fitting time-series models to each series, all the data needed is present in a single array. For example, if you want to generate a set of lagged time series from your original collection of time series, each lagged series can be computed by only looking at a single record in the input RDD.

2.6 5G

The industry future is seen based on the concept of service oriented architecture, where the rigid hierarchical structure is transformed into a more flexible heterogeneous one. The same service interface unites devices and services on different levels and allows them to communicate. This expands the next generation system on two areas simultaneously covering cyber world and physical world resulting in CPS environment. (Colombo et al., 2014)

The best way to provide communication between devices in the industrial environment is a wireless solution such as 5G network. The possibility to move and rearrange machines is no longer restricted by cabling and done with ease which is the most evident advantage.

The 5th generation networks increase significantly the density of communicating devices $1 \times 10^6/\mathrm{km}^2$ and guarantee high transfer rate 10 GB/s to 50 GB/s. (Gupta and Jha, 2015) The development in the field of Time Sensitive Networking (TSN) Ethernet made it possible to have real-time reliable communication with ms response time. This opens the possibility for the process control and monitoring over the wireless network.

Significant advances in the antenna construction allowed to make simple and cheaper connection devices on one hand and provided better energy efficiency on the other. Lifetime of the device on one battery charge is significant limitation for applying wireless devices in the industrial environment. The antenna arrays used for 5G form a precisely directed beam thus significantly reducing the energy used for communication. (Gupta and Jha, 2015) At the same time the quality is improved.

The crucial role of the security for the industrial environment is evident. Such inherited physical features of 5G as directionality, large bandwidth, short range transmission significantly limits the possibility for the intrusion into the network. Another features such as artificial noise and confidential broadcasting enhance the security further. (Yang et al., 2015)

The other important benefit of the 5th generation networks is dynamic slicing. The slicing allocates devices into separate virtual networks over the same physical environment. (Foukas et al., 2017) The allocation is done on the actual demand bringing together units and necessary services. Thus the network cluster has its own transport, security rules, and local mobile processing resources, which is only meaningful inside the cluster. This forms service oriented, reconfigurable, and context aware system for the industrial process control and monitoring.

In the described system, the 5G network is used to collect the real-time data from the number of distributed sensors. The aim is to provide students with experience in configuring devices for the new wireless approach and allocate them into corresponding network layers according to the security requirements and physical specifications.

3. ASSIGNMENTS AROUND THE MINIPLANTS

Three teaching equipment are available for the students to learn to operate the service oriented process automation system: a mixing tank, a three-tank system and a multiple heat exchanger, all connected into the ABB 800xA system. Next the detailed description of the four teaching units with their control strategies and related assignments are presented and discussed. Subsequently a fourth assignment is presented, through which the students learn the modern process control concepts: OPC UA, virtualized operating systems, cloud computing and 5G.

3.1 The Mixing Tank Process and its Control Strategy

The aim of the first assignment is to design and test the control strategy for the mixing tank process. In the process hot and cold water flow to the approximately 300 liter mixing tank, as presented in Figure 3, through the control valves. The flows (magnetic flow-meters) and temperatures are measured from incoming streams. In the mixing tank there are level measurements based on conductivity and pressure, corrected with respect to temperature. Under the tank there is on/off pump that pumps water to the circulation and outflow lines. The pressure measurement after the pump provides the faster process response and safety feature. In both circulation and outflow lines there are magnetic flow meters and control valves.

The aim is to control the tank level with cascade control by adjusting the desired amount of outflow that is controlled by the outlet valve. Sufficient outflow capability is assured by controlling the circulation line pressure after the pump. Tank level measurement along with circulation and outflow line valves are in the Profibus PA fieldbus network. All other measurements and control signals use traditional analog signals: 4-20mA is used for analog inputs and outputs and 0/24V for the digital output.

3.2 The Multiple Heat Exchanger and its Control Strategy

The objective of the second assignment is to make the dynamic model for the heat exchanger, to design and test the control strategy. In the heat exchanger as shown in Figure 4, two adjustable hot and cold inflows are running through the system. Having flow-meters, the input volumetric flow rates are measured and the incoming hot temperature can be read from the temperature sensor.

This system consists of four heat exchangers, named as: EA-101 (Shell and Tube), EA-102 (Coil), EA-103 (Plate), and EA-104 (Double-pipe); also there are four

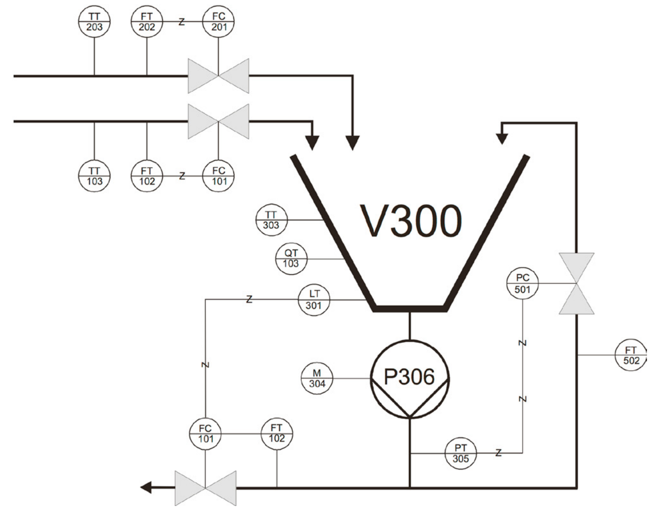

Fig. 3. The influence of pressure and temperature on process supply

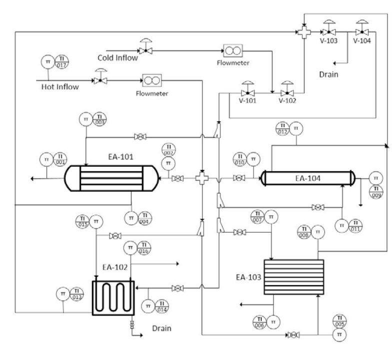

Fig. 4. Process and instrumentation of the heat exchanger system

streams for each heat exchanger that are equipped with temperature sensors. System has the capability of having counter-current or co-current streams by adjusting four pneumatic valves which are working in pairs (counter-current: V101/V103 Open V102/V104 Close and visa versa for co-current).

The aim of this study is to control the hot outflow temperatures by adjusting hot and cold inflows through the four parallel heat exchangers. The study can be narrowed to specific heat exchanger by closing the manual input valves of the other three. Defined on the Profibus PA fieldbus network, there are seventeen analog temperature measurement with two analog inflow (4-20mA) designated for hot and cold inflows adjustment; the four pneumatic valves are output digital signals (0/24V).

3.3 The Three-tank System and its Control Strategy

The objective of the third assignment is to design and test the linearized state space model to control the three-tank system. In the system two pumps and six valves are accompanied with by the main reservoir as shown in Figure 5. Each tank is equipped with pressure level indicator (PLI) and six valves are connecting the tanks together with the main reservoir (FA-104).

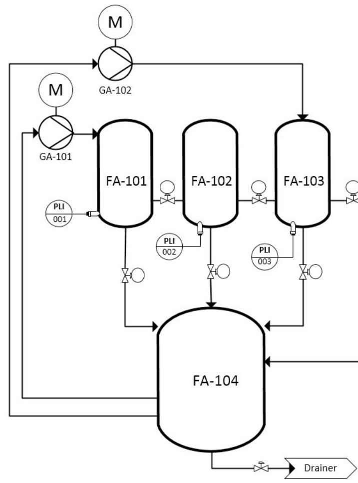

Fig. 5. Process and instrumentation of the three tank system

In this system, pumps are feeding water from the main reservoir to two tanks (FA-101 and FA-103) and tank FA-102 is filled by having the connecting valves open.

Here, the aim is to control the level of the tank FA-102 by controlling the inputs to this tank and all the outflows to the main tank. There are eight digital signal outputs (0/24V) among which six allocated for on/off valves and two for pumps.

3.4 Teaching the Modern Concepts of "Factory of the Future"

The objective of this assignment is to implement cloud computing and OPC UA communication, and access the miniplants through 5G testbed. Students will be able to connect OPC UA server to its local client with a MatrikonOPC UA Wrapper for COM OPC Servers. Since this connectivity is on top of embedded ABB System 800xA, the local clients are open to ABB hierarchy. Further, students can navigate through the projects variable in ABB roots for reading and writing on their miniplants.

OPC UA Wrapper server, on top of ABB system 800xA, can have cloud client. In this part, students will connect the OPC UA server to its cloud client and web server to enable data collection into cloud space. Cloud Client enables various clusters of services including data preprocessing, data storing and data analysis. Students are introduced to Play and Spark frameworks and required to design the front-end for reading and writing to the system.

Moreover, as one of the means of system connectivity, 5G connection provides the opportunity for students to integrate it with Process Automation Systems. Supervised practicing of this connection, eliminates the necessity of wiring and connects the PLCs directly to the Cloud Space to follow the concept of PLC-open. Albeit, this part is still under its final development.

The final assignment introduces the students to the latest service oriented hierarchy of the modern automation systems. The concepts of CPS, IoT, IIot and System of Systems are studied and utilized to provide the fundamental experience. The study programmer also includes separate teaching modules for advanced process control methods and production planning and scheduling.

4. TEACHING PROGRAMME

Teaching programme around the service oriented process automation system is divided into theoretical and practical parts. The theoretical education consists of series of lectures, where the students learn about the automation system requirements, different options for implementations, Open systems architecture, reliability, and safety. In more detail, the Open System Interconnection Model (OSI-Model) with two sets of Transport and Application is presented. It is developed by ISO and considered as a building block for internetworks. In preparation to practical parts and exercises, the topics such as fieldbus, Ethernet, Internet Protocols, OPC UA with ABB wrapper, Control Related Frameworks, 5G, and Security are presented.

Practical education begins by introduction of the ABB 800xA system, including the Aspect & Object, System Topology, Client/Server Network, Engineering Workplace/Plant Explorer, System Configuration, and other related concepts. PLC Programming language on ABB system is practiced through Function Block Diagram (FBD), Structured Text (ST), Sequential Function Charts (SFC), Instruction List (IL), and Ladder Diagram (LD). Here, the students learn also about concepts such as Data Types, Libraries, and Control Modules/Strategies followed by examples regarding Process Graphics, Graphical Shortcuts, Trends, Alarms/Events and Documentation.

After the step wise explanations and supervised practice sessions which include OPC UA connectivity, data collection in cloud, and communication via 5G, students are assigned to groups where they independently implement and test their own projects. Each group is given a manual, to orientate themselves around the physical layer of the selected system from sensors and actuators to the PLC and Cards and the I/O cabins.

The project work includes the controller section, where the students implement the physical layer through right Analog/Digital Inputs and Cards. Subsequently, the groups are implementing the control algorithms according to the specification of the system. The programming language is selected from the list of supported by the ABB 800xA system. Next, groups make the Graphical User Interface (GUI) for their project and connect their defined aspects to the interface for effortless access. Further, each group implements the new taught concepts of FoF such as OPC UA, Cloud Computing, and 5G in their assigned miniplants. The project work consists of four assignments described in Section 3.

The students are required to present the control systems they have developed and implemented in demo sessions, where e.g. the Alarms and Events are tested. Finally, the course is completed by presenting, a detailed report, a learning diary and clear documentation for the implemented project. Feedback and learning diaries are continuously used for improvement of the course.

5. CONCLUSIONS

The unique educational setup that represents the future industrial environment with latest technological advances such as OPC UA, virtualization, cloud computing and 5G network was implemented for training and teaching the future process chemical engineers. ABB Industrial IT Extended Automation System 800xA was set up for centralized data collection, analysis, real-time monitoring, and advanced control. ABB setup included OPC UA, providing a single entry point into a system. The cloud based system included an OPC UA client which allowed access to ABB OPC Server using OPC UA Specifications. Play framework was chosen to build the cloud environment, as it uses a fully asynchronous model, is stateless, and scales simply and predictably in the cloud. 5G network was utilized for communicating data between parts of the setup.

This brings the possibility to provide flexible environment for students to gain practical skills with physical plants by seamless transfer of the results from simulation to the actual system. The setup also provides the shift in students paradigm from the hierarchical thinking to the network structure with instant connectivity.

A set of project works with first three plants combined into this system was introduced to students. The feedback collection process has started to navigate the shortcoming of the applied teaching approach. There are developments going on to enrich the study program to include deep mining methods to the process control, production planning and scheduling.

The presented educational environment will act as a core part of the data valley. The valley concept provides the collaborative workplace for our end-users from Finnish industry and other partners from inside the university.

ACKNOWLEDGEMENTS

This research was supported by the project "5G meets Industrial Internet" financed by Technology Industries of Finland Centennial Foundation and by the project "Bioeconomy Infra" which is a part of Finlands Strategy and Roadmap for Research Infrastructures 20142020.

REFERENCES

Badger, L., Grance, T., Patt-Corner, R., and Voas, J. (2012). Cloud Computing Synopsis and Recommendations. Technical report, National Institute of Standards and Technology (NIST). URL `http://nvlpubs.nist.gov/nistpubs/Legacy/SP/nistspecialpublication800-146.pdf`.

Beghi, A., Marcuzzi, F., and Rampazzo, M. (2016). A Virtual Laboratory for the Prototyping of Cyber-Physical Systems. *IFAC-PapersOnLine*, 49(6), 63–68. doi:10.1016/j.ifacol.2016.07.154.

Boyd, A., Noller, D., Peters, P., Salkeld, D., Thomasma, T., Gifford, C., Pike, S., and Smith, A. (2008). SOA in Manufacturing: Guidebook. Technical report, A MESA International, IBM Corporation and Capgemini. URL `ftp://public.dhe.ibm.com/software/plm/pdif/MESA_SOAinManufacturingGuidebook.pdf`.

Colombo, A.W., Bangemann, T., Karnouskos, S., Delsing, J., Stluka, P., Harrison, R., Jammes, F., and Lastra, J.L. (eds.) (2014). *Industrial Cloud-Based Cyber-Physical Systems*. Springer International Publishing, Cham. doi:10.1007/978-3-319-05624-1.

Foukas, X., Patounas, G., Elmokashfi, A., and Marina, M.K. (2017). Network Slicing in 5G: Survey and Challenges. *IEEE Communications Magazine*, 55(5), 94–100. doi:10.1109/MCOM.2017.1600951.

Gupta, A. and Jha, R.K. (2015). A Survey of 5G Network: Architecture and Emerging Technologies. *IEEE Access*, 3, 1206–1232. doi:10.1109/ACCESS.2015.2461602.

Hellinger, A. and Seeger, H. (2011). Cyber-Physical Systems: Driving force for innovation in mobility, health, energy and production. Technical report, National Academy of Science and Engineering. URL `http://www.acatech.de/fileadmin/user_upload/Baumstruktur_nach_Website/Acatech/root/de/Publikationen/Stellungnahmen/acatech_POSITION_CPS_Englisch_WEB.pdf`.

Honc, D., Sharma K., R., Abraham, A., Dušek, F., and Pappa, N. (2016). Teaching and Practicing Model Predictive Control. *IFAC-PapersOnLine*, 49(6), 34–39. doi:10.1016/j.ifacol.2016.07.149.

ITU (2005). ITU Internet Reports: The Internet of Things. Technical report, International Telecommunication Union (ITU). URL `https://www.itu.int/net/wsis/tunis/newsroom/stats/The-Internet-of-Things-2005.pdf`.

Kagermann, H., Wahlster, W., and Helbig, J. (2013). Recommendations for implementing the strategic initiative INDUSTRIE 4.0. Technical report, National Academy of Science and Engineering. URL `http://www.acatech.de/fileadmin/user_upload/Baumstruktur_nach_Website/Acatech/root/de/Material_fuer_Sonderseiten/Industrie_4.0/Final_report__Industrie_4.0_accessible.pdf`.

Karnouskos, S. and Colombo, A.W. (2011). Architecting the next generation of service-based SCADA/DCS system of systems. In *37th Annual Conference of the IEEE Industrial Electronics Society*, 359–364. IEEE. doi:10.1109/IECON.2011.6119279.

Lee, E.A. and Seshia, S.A. (2017). *Introduction to Embedded Systems: A Cyber-Physical Systems Approach*. MIT Press, second edition.

Mäntylä, M. (2016). Three narratives on digitalization. WorkingPaper 1, Aalto University.

Shariati, S. and Abel, D. (2016). Model Predictive Control in two days: Educating a new way of thinking. *IFAC-PapersOnLine*, 49(6), 40–45. doi:10.1016/j.ifacol.2016.07.150.

Sharma, A., Jelemenský, M., Valo, R., Kalúz, M., and Fikar, M. (2016). Process Control Education using a Laboratory Separation Process. *IFAC-PapersOnLine*, 49(6), 4–9. doi:10.1016/j.ifacol.2016.07.143.

Taleb, T., Ksentini, A., and Jantti, R. (2016). "Anything as a Service" for 5G Mobile Systems. *IEEE Network*, 30(6), 84–91. doi:10.1109/MNET.2016.1500244RP.

Yang, N., Wang, L., Geraci, G., Elkashlan, M., Yuan, J., and Renzo, M.D. (2015). Safeguarding 5G wireless communication networks using physical layer security. *IEEE Communications Magazine*, 53(4), 20–27. doi:10.1109/MCOM.2015.7081071.