DLR-IB-DW-JE-2018-26

Overview of Software Development Topics for the Digitalization of Industry

Diana Peters and Philipp Matthias Schäfer

DLR Deutsches Zentrum für Luft- und Raumfahrt

Overview of Software Development Topics for the Digitalization of Industry

Diana Peters and Philipp Matthias Schäfer

February 1, 2018

Contents

1 Introduction

At the beginning of the 2010s, governments and industry consortiums intensified their efforts to promote the digitalization of industry. They founded various initiatives for this purpose. Germany's "Plattform Industry 4.0", France's "Alliance Industrie du Future", Japan's "Robot Revolution Initative", and the "Industrial Internet Consoritum" are some of the big ones. There are a lot more on various levels of specialization and geographical affiliation. Two maps published by the European Union exemplify this: [1] [2].

These efforts come in the wake of several technological advances. Cheaper and smaller sensor and networking equipment enable the supervision of every detail in production and operation. Commoditized computing and storage resources allow to process the incurring data. Improved data processing methods make it possible to come to decisions based on that data. Here, machine learning is of particular note. Portable computers—tablets, smartwatches, and smartglasses—provide location independent access to information for humans. In Section 2 we introduce these conceptual building blocks of the digitalization of industry.

Employing these technologies allows to simplify and automate more processes than before. Some examples are automatic maintenance scheduling, automatic quality control, and location independent information delivery to workers.

There are various software tools that belong to the before mentioned conceptual categories. This includes platforms, frameworks, protocols, and ontologies. In Section 3 we describe such tools. We list concrete instances in the appendices.

Finally, there are abstract guidelines that are relevant to software developement for the digitalization of industry. They come in the form of standards, recommendations, and organizational frameworks. Standard bodies and industrial consortiums publish these guidelines. We discuss both publications and their publishing organizations in Section 4. Again, we list concrete instances in the appendices.

In this paper, we give definitions of the terms used in the context of the digitalization of industry. In addition, we describe the state of the art restricted to the software side of the digitalization of industry.

2 Concepts

2.1 Networked Devices

Given cheap and miniaturized networking equipment, any electrical device—whether RFID tags, sensors, actuators, or compounds thereof—can be connected to a local network or the internet. They can then remotely receive commands and send data. This spawned the idea of the "Internet of Things" [23] [25], a term coined by Kevin Ashton in 1999 [4]: Machines, sensors, and even parts in production get connected and provide a slew of information about themselves and their environment, including their bearers or users.

The network interfaces of physical devices form connections between the digitial and the analog—or between the cyber and the physical—world. They are thus the basis of the digitalization of industrial processes.

For the purpose of this paper, only the software side of these network interfaces is of interest.

2.2 Compute and Storage Resources

Virtualizing computing and storage resources allows their flexible allocation, which leads to less idle resources and thus cost reduction. Offerings of virtualized computing and storage resources are called Infrastructure as a Service (IaaS). These services make one-time use of expensive hardware affordable.

On top of this infrastructure can run the basic components of applications, for example load balancers, web servers, and databases. Offerings of this type are called Platform as a Service (PaaS). These services are interesting for application developers that want to delegate part of the management of basic components.

Finally, actual software, for example CRMs and ERPs, can be built upon these basic application components. Offerings of end user ready software are called Software as a Service (SaaS).

So there are four levels of abstraction: the hardware, the virtualization layer, the platform layer, and the end user software. An enterprise can decide which of these levels it wants under its direct control. There are software frameworks that allow to set up each level on on-premises hardware.

Starting at the platform level, there are commercial offerings designed for general industry or even industry specific problems.

The use of external services as described in the previous paragraphs is called Cloud Computing [1]. Cloud Computing allows a company to outsource the management of IT infrastructure up to one of the above mentioned levels.

Cloud Computing is associated with higher latencies than on-premise computing. In situations with small, specialized computations, latency can be reduced by moving the computation closer to the actors and sensors, i.e. to the border of the network. This approach is called Fog Computing [5] [20].

In addition to providing lower latencies, Fog Computing allows to keep sensitive data on-premise. Sadeghi et al. give an overview of the security challenges that arise with the industrial internet of things [19].

2.3 Computing Methods

While new methods get developed and existing methods are improved all the time, the availability of more and more computing resources as well as data has led to considerable advances in machine learning research [12]. Computer Vision is a field, relevant to the digitalization of industry, that profited a lot from these developements.

2.4 Portable Computers

Another result of advancements in miniaturization of computing and networking equipment is the advent of portable computing devices, that started at the end of the last century. Tablet computers, smartphones, smartwatches, and smartglasses all fall into this category.

These portable computers are one kind of networked devices. This allows them to provide location independent access to information, in the case of smartwatches and smartglasses even with little to no limitations to the use of the users hands.

Smartglasses can be further divided into virtual reality (VR) glasses and augmented (or mixed) reality (AR) glasses. The former allow the wearer to see a completely virtual reality (VR), while the latter superimpose images on the real world. Both have applications in an industrial context. VR glasses can be used to design or train in a virtual setting, while AR can be used to superimpose information in manufacturing or logistics settings.

Some of these devices do not only provide information for the user but also act as sensors and can detect for example tiredness or stress which can result in the suggestion to take a break or even prevent a machine from being operated by a tired worker [16].

2.5 Cyber-Physical Systems

The combination of a physical device and closely associated software, whose states influence each other, forms a cyber-physical system, a term coind by Helen Gill [15]. The associated software itself can be any combination of a virtual representation of the physical device and business logic. In the special case that the virtual representation faithfully mimics the physical device, the virtual representation is called a digital or virtual twin.

Knight et al. provide a formal definition for *cyber-physical system* in [13].

Making every machine, tool, and produced part a cyber-physical system is the driving vision behind the digitalization of industry.

3 Tools

Software systems for the digitalization of industry consist of several parts. Communication protocols enable the data transfer from and to networked devices. This data is sent and received by software based on frameworks running on platforms, as defined in the introduction.

The following sections give an overview of communication protocols, software frameworks, and computing platforms that are relevant for the digitalization of industry.

[1] The term arguably derives from the use of clouds to depict networks in diagrams.

3.1 Communication Protocols

Networked devices are usually set up to communicate using the internet protocol (IP) on the internet layer and TCP, UDP or SCTP on the transport layer. Security is usually provided by TLS/SSL and DTLS on the transport layer or SASL on the application layer. On the application layer, there are multiple protocols in common use [18], [14]. Some of these protocols use HTTP as an additional layer. XML and JSON, as well as binary formats, are used.

In [18], Nitin Naik also states that different protocols and standards are needed, because the requirements vary so much that one protocol can not fit them all. The protocols described below indeed all address different concerns—requirements of a very big sensor network with limited power of the devices are fundamentally different from a set of machine tools that are supposed to work with each other or provide self-descriptions for planning processes. So there remains the question if a "one fits all" protocol is possible.

Appendix A provides a list of protocols suitable for communication between networked devices and software platforms.

3.2 Platforms

A platform as defined in section 2.2 offers access to compute and storage resources. Software running on such a platform can communicate (receive and send data) with networked devices or other software systems. The ingested data can be processed or stored. The results of processing the data can be commands sent out to networked devices, data sent to other software systems, or information provided to humans in visual form.

Relevant platforms can be broadly categorized into general purpose platforms, general industrial platforms, and domain specific industrial platforms. Lists for each of these categories can be found in Appendix B.

Almost all platform providers are commercial entities, though with the European Grid Initiative[2] there is a provider without a pure commercial background.

In addition to Platform as a Service providers, there are frameworks, such as OpenStack[3] and CloudStack[4], that enable the setup of on-premises platforms.

3.3 Frameworks

Frameworks are sets of methods, software applications, and software libraries that allow a user to develop full applications. There are frameworks for software on various levels spectrum, from the infrastructure level, over the platform level to the software level.

3.3.1 IoT Frameworks

In the platform section we already mentioned some frameworks that allow to host local platforms. IoT frameworks form another class relevant to the digitalization of industry. Derhamy et al. [6] give an overview over existing IoT frameworks and platforms. Platforms are already covered in a previous sections and listed in Appendix B.

Derhamy et al. classify frameworks into three classes according to which network architectures they support: Global Cloud, Peer to Peer, and Local Cloud. The main difference between the categories Global Cloud and Local Cloud is that frameworks in the latter category provide for communication between instances of platforms realized by them.

Another way to classify the frameworks is the separation into home automation and industrial automation frameworks. The classification has to be based on intent, since given enough effort most frameworks can be used for either.

The Appendix C lists popular IoT frameworks. For their classification, we refer to [6].

[2] https://www.egi.eu
[3] https://www.openstack.org/
[4] https://cloudstack.apache.org/

The topic of frameworks is intertwined with many of the other covered in this paper. Many of the mentioned frameworks follow certain standards (see Section 4), for example with respect to the protocols they use (see Section 3.1).

3.4 Ontologies

Communication between various devices is an important part of the digitalization of industry. How data is transfered is formalized by protocols, as covered in Section 3.1. To understand the data, the receiving end must also know its structure and semantics. Ontologies provide developers of different systems with a formal description of that structure and semantics.

Studer et al. [21] define an ontology as "a formal, explicit specification of a shared conceptualization.". Guarino et al. discussed this definition in [10].

An ontology in software context is employed in some application or system. Wache et al. [22] identified three different approaches to do that:

- single ontology approach: all information sources share the same ontology; changes in the semantics of one source require a change in the overall ontology and mostly in the other sources as well
- multiple ontology approach: every information source has its own ontology and there are mappings between the ontologies; changes in one source require the change of the related ontology and the mappings that affect this ontology
- hybrid ontology approach: this is like the multiple ontology approach but the mappings are minimized and there is a shared vocabulary that affects all ontologies; the single ontologies are specialized extensions of the overall vocabulary and depend on it (the entities in the local ontologies are defined with regard of the shared vocabulary); this approach intends to minimize the impact of a change in a single information source

These three categories were extended by a fourth one in [7]. There, Ekaputra et al. surveyed existing OBDI (ontology-based data integration) applications and found several that used a hierarchy of ontologies like a hybrid approach but where the local ontologies existed before the global one and were therefore independent from it.

Schema languages, such as XML Schema [9] and JSON Schema [24], allow for the definition of the simplest useful ontologies; those that only define structure. Modern ontology languages, like OWL2 [8], are far more expressive and provide for the creation of ontologies one can reason about.

4 Standard Bodies and Industry Consortiums

There are various standard bodies and industrial consortiums whose publications are relevant to the digitalization of industry. Many of these organizations exist for more than a decade, but in particular some industry consortiums were founded during the recent drive for the digitalization of industry.

Industry consortiums usually serve three important purposes: guidance of their members (and possibly others), fostering cooperation between them, and enabling the interoperability between solutions of different providers.

Guidance comes in the form of handbooks and training on how to implement new methods.

Cooperation can be fostered by interaction of members during training or at conferences, as well as, by providing shared facilities for development and testing.

To help interoperability, standards are developed, sometimes by consortiums, and then published, usually by established standards bodies.

In Appendix E we list standard bodies and industrial consortiums relevant to the digitalization of industry. Standards, recommendations and organizational frameworks can be found in Appendix F. This appendix, in particular, can only be a small, subjective selection. The digitalization of industry relies heavily on many preexisting technologies, that can not possibly—and need not—all be listed here.

A Communication Protocols

A selection of communication protocols relevant to IoT:

Message Queue Telemetry Transport (MQTT)
`https://www.oasis-open.org/standards#mqttv3.1.1`

Constrained Application Protocol (CoAP)
`https://tools.ietf.org/html/rfc7252`

Advanced Message Queuing Protocol (AMQP)
`https://www.amqp.org/`

Hypertext Transfer Protocol (HTTP)
`https://tools.ietf.org/html/rfc7230` (HTTP/1.1)
`https://tools.ietf.org/html/rfc7540` (HTTP/2)

Extensible Messaging and Presence Protocol (XMPP)
`https://xmpp.org/`

B Platforms

B.1 General Purpose Computing Platforms

The following list shows notable general purpose computing platforms. While five of these six are commercial providers, the European Grid Initiative is a federated platform of European research organizations that provides researchers with access to resources.

Amazon Web Services
`https://aws.amazon.com`

European Grid Initiative
`https://www.egi.eu`

Google Cloud Platform
`https://cloud.google.com`

IBM Cloud
`https://www.ibm.com/cloud`

Microsoft Azure
`https://azure.microsoft.com`

SAP Cloud Platform
`https://cloudplatform.sap.com`

B.2 Industrial Computing Platforms

The following list shows notable industrial computing platforms that have no focus on specific industries.

Adamos
`https://en.adamos.com/`

Bosch IoT Suite
`https://www.bosch-iot-suite.com/`

Cumulocity
`https://www.cumulocity.com/`

GE Provides
`https://www.ge.com/digital/predix`

Inductive Automation
`https://inductiveautomation.com/solutions/iiot`

SAP Cloud Platform for the Internet of Things
`https://www.sap.com/products/iot-platform-cloud.html`

Siemens MindSphere
`https://www.siemens.com/global/en/home/products/software/mindsphere.html`

ThingSquare
`http://www.thingsquare.com/`

ThingWorx
`https://www.ptc.com/en/products/iot/thingworx-platform`

Xively
`https://www.xively.com/`

B.3 Specialized Computing Platforms

There are various platforms specialized for industrial sectors or even just small groups of companies. The selection represents a very tiny sample of the existing platforms.

agXplatform
`http://www.agxplatform.com/`
Platform for the agriculture sector

BoostAeroSpace
`http://www.boostaerospace.com/`
Platform for the aerospace sector

Maritime Connectivity Platform
`http://maritimecloud.net/`
Platform for the maritime sector

C IoT Frameworks

A selection of IoT frameworks:

AllJoyn
`https://openconnectivity.org/developer/reference-implementation/alljoyn`

Arrowhead
`http://www.arrowhead.eu/`

AXCIOMA
`https://www.axcioma.com/`

IoTivity
`https://www.iotivity.org/`

IzoT
`https://www.echelon.com/izot-platform`

Kaa
https://www.kaaproject.org/

Thread
https://threadgroup.org/

D Ontologies

A selection of industry related ontologies:

eClass
https://www.eclass.eu/
Product classification and description

Model-Based Space Engineering Ontology [11]
https://zenodo.org/record/50670
An ontology for Model-Based Systems Engineering in the space sector.

Lists of general ontologies:

@W3C
https://www.w3.org/wiki/Lists_of_ontologies

@Protege
https://protegewiki.stanford.edu/wiki/Protege_Ontology_Library

E Standard Bodies and Industry Digitalization Consortiums

A selection of relevant standard bodies and industry digitalization consortiums:

International Organization for Standardization
https://iso.org
The International Organization for Standardization is a standard body that works on an international level, backed by a majority of countries. It releases and sells access to standards and norms.

Industrial Internet Consortium
https://www.iiconsortium.org/
The Industrial Internet Consortium publishes recommendations[5] and is a forum for coordination in the realm of the digitalization of industry for its members.

Plattform Industrie 4.0
https://www.plattform-i40.de
Plattform Industrie 4.0 is a german industry consortium for the promotion of industry digitalization.

Object Management Group
http://omg.org
The Object Management Group creates publishes specifications for data formats and languages, UML being one notable example.

[5] http://www.iiconsortium.org/white-papers.htm

F Organizational Frameworks

The following two publications with coarse reference architectures for industry digitalization.

- Industrial Internet Reference Architecture [17]
- Reference Architektur Modell Industry 4.0 [3]

References

[1] Map overview of digitising european industry initiatives across europe. https://ec.europa.eu/digital-single-market/en/news/map-overview-digitising-european-industry-initiatives-across-europe. Accessed: 2017-11-08.

[2] Overview of european initiatives on digitising industry. http://ec.europa.eu/information_society/newsroom/image/document/2016-16/overview_of_digitising_industry_with_links_15202.pdf.

[3] Reference architecture model industrie 4.0.

[4] Kevin Ashton. That 'internet of things' thing. http://www.rfidjournal.com/articles/view?4986, 2009. Accessed: 2017-11-09.

[5] Flavio Bonomi. Connected vehicles, the internet of things, and fog computing. In *The Eighth ACM International Workshop on Vehicular Inter-Networking (VANET), Las Vegas, USA*, pages 13–15, 2011.

[6] Hasan Derhamy, Jens Eliasson, Jerker Delsing, and Peter Priller. A survey of commercial frameworks for the internet of things. In *2015 IEEE 20th Conference on Emerging Technologies & Factory Automation (ETFA)*. IEEE, sep 2015.

[7] Fajar J. Ekaputra, Marta Sabou, Estefanía Serral, Elmar Kiesling, and Stefan Biffl. Ontology-based data integration in multi-disciplinary engineering environments: A review. *OJIS*, 4(1):1–26, 2017.

[8] Motik et al. Owl 2 web ontology language structural specification and functional-style syntax (second edition), 2012. https://www.w3.org/TR/owl2-syntax/.

[9] Fallside and Walmsley. Xml schema part 0: Primer second edition, 2004. https://www.w3.org/TR/xmlschema-0/.

[10] Nicola Guarino, Daniel Oberle, and Steffen Staab. What is an ontology? In *Handbook on Ontologies*, pages 1–17. Springer Berlin Heidelberg, 2009.

[11] Christian Hennig, Alexander Viehl, Benedikt Kämpgen, and Harald Eisenmann. Ontology-based design of space systems. In *Lecture Notes in Computer Science*, pages 308–324. Springer International Publishing, 2016.

[12] M. I. Jordan and T. M. Mitchell. Machine learning: Trends, perspectives, and prospects. *Science*, 349(6245):255–260, jul 2015.

[13] John Knight, Jian Xiang, and Kevin Sullivan. A rigorous definition of cyber-physical systems. *Trustworthy Cyber-Physical Systems Engineering (2016)*, 47, 2016.

[14] Sylvain Kubler, Manik Madhikermi, Andrea Buda, and Kary Främling. QLM messaging standards: Introduction and comparison with existing messaging protocols. In *Studies in Computational Intelligence*, pages 237–256. Springer International Publishing, 2014.

[15] Edward Lee. The past, present and future of cyber-physical systems: A focus on models. *Sensors*, 15(3):4837–4869, feb 2015.

[16] Ping Li, Ramy Meziane, Martin J.-D. Otis, Hassan Ezzaidi, and Philippe Cardou. A smart safety helmet using IMU and EEG sensors for worker fatigue detection. In *2014 IEEE International Symposium on Robotic and Sensors Environments (ROSE) Proceedings*. IEEE, oct 2014.

[17] Lin, Miller, Durand, Bleakley, Chigani, Martin, Murphy, and Crawford. The industrial internet of things volume g1: Reference architecture. `http://www.iiconsortium.org/IIC_PUB_G1_V1.80_2017-01-31.pdf`, 2017.

[18] Nitin Naik. Choice of effective messaging protocols for IoT systems: MQTT, CoAP, AMQP and HTTP. In *2017 IEEE International Systems Engineering Symposium (ISSE)*. IEEE, oct 2017.

[19] Ahmad-Reza Sadeghi, Christian Wachsmann, and Michael Waidner. Security and privacy challenges in industrial internet of things. In *Proceedings of the 52nd Annual Design Automation Conference on DAC 15*. ACM Press, 2015.

[20] Ivan Stojmenovic and Sheng Wen. The fog computing paradigm: Scenarios and security issues. In *Proceedings of the 2014 Federated Conference on Computer Science and Information Systems*. IEEE, sep 2014.

[21] Rudi Studer, V.Richard Benjamins, and Dieter Fensel. Knowledge engineering: Principles and methods. *Data & Knowledge Engineering*, 25(1-2):161–197, mar 1998.

[22] H. Wache, T. Vögele, U. Visser, H. Stuckenschmidt, G. Schuster, H. Neumann, and S. Hübner. Ontology-based integration of information - a survey of existing approaches. pages 108–117, 2001.

[23] Andrew Whitmore, Anurag Agarwal, and Li Da Xu. The internet of things—a survey of topics and trends. *Information Systems Frontiers*, 17(2):261–274, mar 2014.

[24] Austin Wright and Henry Andrews. Json schema: A media type for describing json documents. Technical Report draft-handrews-json-schema-00, sInternet Engineering Task Force, November 2017. Work in Progress.

[25] Li Da Xu, Wu He, and Shancang Li. Internet of things in industries: A survey. *IEEE Transactions on Industrial Informatics*, 10(4):2233–2243, nov 2014.