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# CONTENT

## Guest Contributions



## Themes





# Editorial

Dear friends and partners of the IOSB,

Industry 4.0 and its application on the shopfloor are underway. New buzzwords, such as Industrial Internet of Things (IIOT), Digital Twin and Artificial Intelligence (AI), are becoming common parlance. In this issue of visIT – Fraunhofer IOSB's inhouse magazine – our authors seek to shed light on some of these new trends and describe how Industry 4.0, IIoT and digital twins fit into the bigger picture.

Our guest authors, Jivka Ovtcharova and Rainer Drath, are both experts in digital engineering. They discuss their own R&D-results, important aspects of dealing with digital twins, their weak points and the requirements that they have to fulfill. As they explain, digital twins have to cover issues across the lifetime of the related assets. In Industry 4.0 and its related working groups, the digital twin is linked to the asset administration shell, which is regarded as the collection of meta-models and the communication layer of a physical asset.

The authors from our industrial automation site in Lemgo explain how digital twins may be used for alarm management in complex and distributed automation systems. Clearly, digital twins require secure communication, not only for their configuration but especially for their run-time data. Jens Otto and Felix Specht describe one industrial use case which illustrates how companies apply OPC UA and thus fulfill the requirements of IEC 62443. Julius Pfrommer takes a closer look at OPC UA publish/subscribe features and their combination with real-time capabilities based on Time Sensitive Networking (TSN).

Ljiljana Stojanovic focusses on another aspect of digital twins: the meaning of data and its processing close to the asset, e.g. on an edge device. This 'semantic edge' is used to communicate with the industrial asset, such as a machine, perform local processing (like edge analytics) and transfer pre-processed data to the cloud. Christian Kühnert describes the application of cloud services for machine learning and data analytics. The IOSB has developed this platform because most manufacturing companies do not have the capabilities to analyze large amounts of sensor data: manufacturing companies may use it on their own premises or hosted on IOSB-servers.

Thomas Usländer's article covers the important topic of engineering digital twins. During every phase of an asset's life cycle, the digital representation must be synchronized as closely as possible with the status of the real-world object. Furthermore, digital twins must support the evaluation of past situations and simulation of future situations by means of prognostic models which are always connected to the physical asset. Thus, digital twins need the deployment and run-time environment to be aware of the status of its asset at all times.

Smart factories will be connected worldwide and consist of smart assets and their digital twins. These describe, e.g. manufacturing capabilities, skills and capacity levels. In their article, Byung Hun Song from our Korean partner KETI and Kym Watson explain the concept of a smart factory web, which is simultaneously our testbed in the Industrial Internet Consortium.

We hope this edition of visIT gives you a comprehensive overview of the many facets of smart assets and their digital representations, their applications and benefits.

Karlsruhe, April 2018

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# BEYOND THE DIGITAL TWIN – MAKING ANALYTICS COME ALIVE

We live in exciting times. Digitalization is fundamentally transforming the world in which we live and work. Further, faster, higher, but where are we going? What challenges do we face and how should we handle them? A knowledge of history is key to helping us shape the future. The pioneering era of the space exploration began around 60 years ago. At that time, the US National Aeronautics and Space Administration (NASA) was grappling with the challenge of designing objects that could travel so far away they would be beyond the human ability to see, monitor or modify them directly. NASA's innovation was the "digital twin" of a physical system – a comprehensive digital double which people could use to operate, simulate and analyze an underlying system led by physics.

The notion of a "digital twin" is now being widely adopted. It is rapidly becoming the technology of choice for virtualizing the physical world. As versatile and powerful as digital technologies may be, the original purpose of the digital twin remains unchanged: to enable people to study problems more easily, get to the point, understand, and proceed pragmatically and rapidly. The "Internet of Things" is becoming the "Internet of Twins" – strengthening the "front-end" of all we do, making it more dynamic, faster-learning, and also highly interactive. The digital twin offers us excellent opportunities to investigate the unexpected and discover the very best solutions – true to the motto "It is not the technology that changes the world but the way people use it".

But, what is the digital twin exactly? Fundamentally, it is a virtual representation, an embodiment of an asset of any type, material or non-material – including everything from power turbines to services and maintenance. The digital twin is described by the structure and behavior of connected "things" generating real-time data. That data is analyzed, usually in the cloud, and combined with other data related to the running environment around it. It is then presented to users from different perspectives and in a variety of roles, so they can remotely understand its status, its history, its needs, and interact with it to do their jobs.

The interfaces to external systems and validation environments with consideration of all relevant resources and processes ensure high-level connectivity and are key. For example, using the digital twin, it is possible to validate operational concepts for production systems in real-time, for manual and automatic operation, and for configuration via intuitive man-machine interfaces (e.g. web surface, haptic interaction devices). This makes it easier to take decisions based on up-to-date, transparent information. Thus, by merging real and virtual environments, intelligent commissioning of production can be used to generate forecasts based on real-time data from the shop-floor. How does it work? A ready-to-use solution at the Industry 4.0 Collaboration Lab of the Institute for Information Management in Engineering (IMI) at the Karlsruhe Institute of Technology (KIT), Germany, offers a good example. The use case of a digital twin of a milling machine used for process optimization and networking in virtual reality, while taking account of resource flows, demonstrates the practical advantages of the proposed solution by increasing productivity more than 20 percent (Fig. 1).

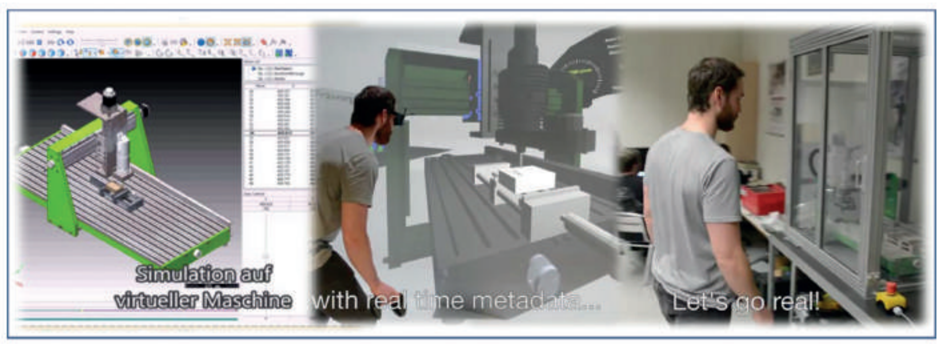


Fig. 1: Digital twin of a milling machine for real-time process optimization.

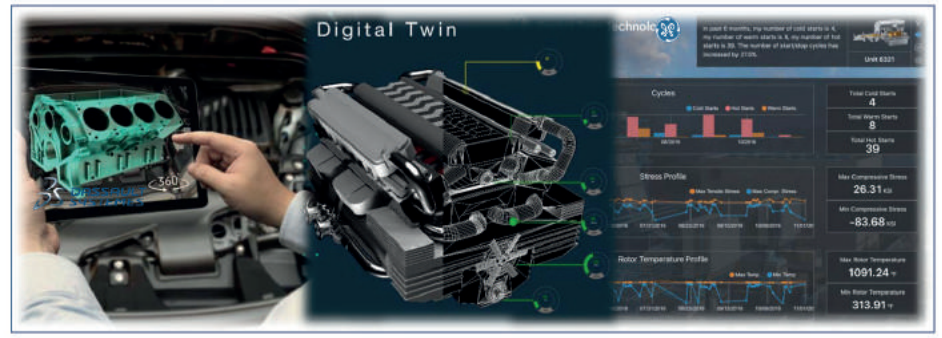


Fig. 2: Status quo of industrial implementation.

Fig. 3: Preconditions for mature and widespread implementation.

Systems which make it easier to gain a unique, deep knowledge of assets and their behaviors throughout the life cycle will pave the road to achieving new levels of optimization and business transformation. For example, we want the physical build to return data to its digital twin through sensors so the digital twin contains all the behavioral information we would have if we inspected the physical build itself.

According to the German Association for Information Technology, Telecommunications and New Media (BITKOM), digital twins in manufacturing industry will have a combined economic potential of more than € 78 bn by 2025. However, this potential can only be achieved if digital twins are implemented in a comprehensive and self-optimizing manner which enables them to adapt to future changes. Current studies show that mature and widespread implementation has not yet taken place (Fig. 2). There are three main weak points to be discussed:

- model semantics of digital twins is mostly geometry driven
- analytics are aligned but not embedded into the model
- simulation and user-interaction are offline.

To overcome current limitations, the following three conditions must be fulfilled (Fig. 3):

- model semantics must be usage driven and adaptive
- analytics should be embedded and work in runtime
- implementation should go along with experiments and experiences.

Implementing digital twins demands that we put real problems "into the sandpit" of business units, think, try out, create "all-in-one", apply emerging digital technologies playfully and quickly, test new solutions in runtime to gain experience fast and transform knowledge into actions and skills. The time to act is now! We invite you to join us in establishing "German Digital Twin Engineering" as a trademark.

Guest

# THE DIGITAL TWIN: THE EVOLUTION OF A KEY CONCEPT OF INDUSTRY 4.0

Industry 4.0 [1], the next industrial revolution has arrived – launching Internet technologies into production environments and introducing the spirit and mindset of apps, software driven value creation and the network economy. A flood of new terms has arisen together with this new spirit, e.g. Digital Twin, Asset Administration Shell or I4.0 component. Interestingly, some of these new terms already existed before Industry 4.0 and are being silently redefined, causing misunderstandings and confusion. However, non-harmonized terms hinder innovation, e.g. the term "digital twin" has currently three different interpretations, highlighting the fact that the meaning of this term has evolved and, indeed, is still evolving.

The digital twin (in German: digitaler Zwilling) was first defined by NASA in 2010 [2] as a simulation of a vehicle or system that uses the best available physical models to mirror the life of its flying twin. Its meaning is all about a highly-detailed simulation model of spacecraft or aircraft which tries to reproduce its physical behavior as close as possible in the virtual world.

Over time, "digital twin" became a hot marketing term, applied to a variety of simulation tools for machine or plant simulation. A powerful marketing campaign conducted by Siemens gave the term a second interpretation: it came to mean a dynamic 3D model, e.g. of a production unit, machine, or car, including simulation. The new focus was on the simulated and visible 3D model. This interpretation is currently state-of-the-art and shared by a broad industrial audience from vendors to users. But in fact, looking into the technical implementation, this is still Industry 3.0 technology, useful for many use cases, but it is not Industry 4.0.

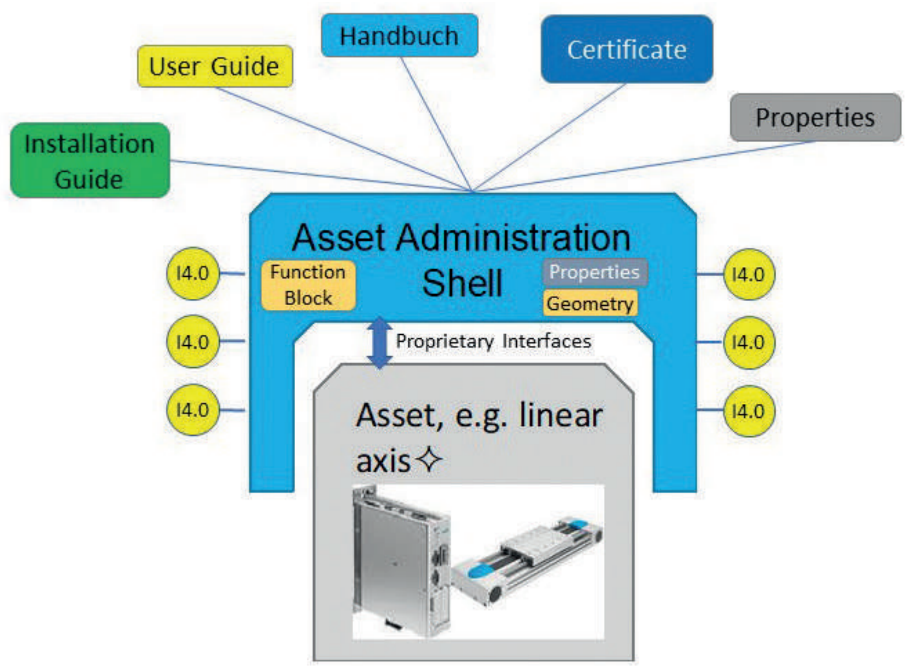


Fig. 1: The future digital twin/administration shell: a software layer on top of a physical asset including data and interfaces.

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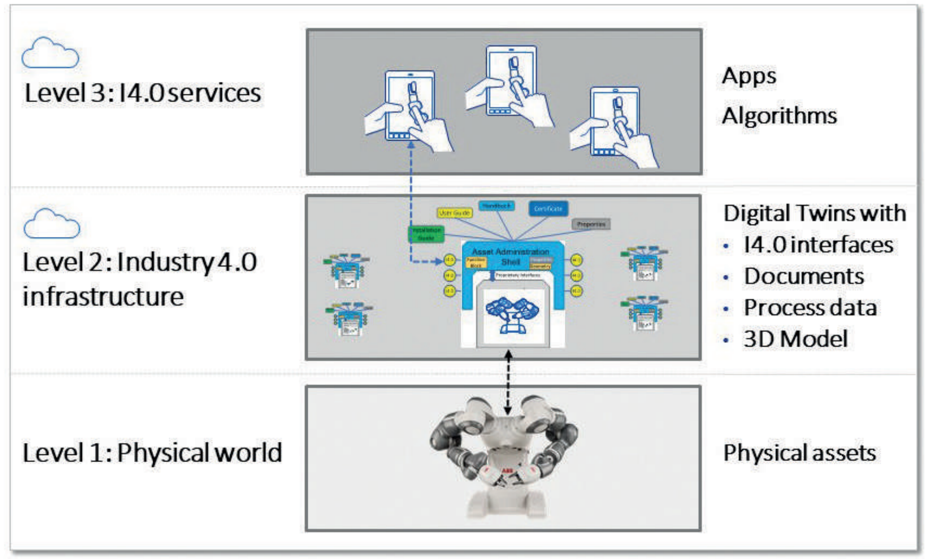


Fig. 2: Three-level concept of a cyber-physical system [4].

The evolution is ongoing. The term "digital twin" is slowly changing its meaning yet again. In a digital future, we will need digital twins as comprehensive physical and functional models for every physical asset [3], e.g. a component, product or system. Step-by-step, the digital twin will cover all the useful information which is relevant across the lifetime of the related asset, from the idea to the engineering, logistics, operation, maintenance, reuse and destruction. A future digital twin may contain a simulation model, but also a 3D model, hundreds of properties, historical data, handbooks, installation guidelines, proprietary function blocks, interlockings, state models, alarm and event definitions etc. Friends of the first or second interpretation may be surprised to hear that it might even have no simulation model at all, e.g. for static assets. It will be stored in a future Industry 4.0 infrastructure, be searchable, explorable, associated with and sometimes connected to its real counterpart. It will not be hidden in proprietary simulation tools. Sales tools, simulation tools, engineering tools, certification tools, maintenance tools etc. may connect to digital twins for sales, engineering, certification, maintenance, simulation or optimization purposes, sometimes long before the related real assets are ordered. It will be possible to associate delivered real devices with their individual digital twin whenever necessary at a later date.

Hence, the digital twin will become a powerful electronic data object with interfaces: it will hold or reference all useful data (see Fig. 1), some data will be semantically standardized (e.g. properties, geometry, topology), other data will be of a proprietary nature (e.g. ABB function blocks). Internally, the digital twin will communicate with its physical asset, e.g. via proprietary interfaces. However, externally, it will communicate via well-defined Industry 4.0 interfaces.

The future digital twin will incorporate both data and interfaces and be similar to a software driver – but far more. It will be a multi-facetted digital counterpart of the real asset, embedded in the Industry 4.0 ecosystem, access point for a new generation of apps and algorithms, mediator between future Industry 4.0 services and the real world. Fig. 2 shows the digital twin in the middle of the tree layer concept of a cyber-physical system [4] in an Industry 4.0 environment.

And what is the Asset Administration Shell (AAS) [5]? According to [6], it contains the information and I4.0 interfaces for an asset. Sounds similar to the digital twin, doesn't it? This is exactly what [6] proposes: the AAS will become synonymous with the digital twin in its future, fully enhanced version. As soon as the meaning of the digital twin finally morphs into the third interpretation, the differences between it and the AAS will disappear.

And what is an Industry 4.0 component? It is the physical asset together with its Asset Administration Shell/digital twin. It is an Industry 4.0 enabled device, that can register itself in the I4.0 network and be identified, explored and processed via Industry 4.0 interfaces.

Finally, the evolution of the term "digital twin" offers a powerful illustration of the upcoming revolution. The future digital twin, in combination with cloud technology, apps and algorithms, has the potential to revolutionize every aspect of industry because it touches every aspect. The possibilities are endless, the digital twin is only the beginning.

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# THE DIGITAL TWIN – A KEY TECHNOLOGY FOR INDUSTRY 4.0

Currently, the digital twin (see Fig. 1) is an emerging technology which is being discussed in several domains. The concept is based on modeling assets with all their geometrical data, kinematic functionality and logical behavior using digital tools. The digital twin refers directly to the physical asset and allows it to be simulated, controlled and improved. According to Gartner, "less than 1 percent of the physical machines and components in use today are modeled such that the models capture and mimic behavior" [1].

At the moment, digital twins are being discussed in Industry 4.0 working groups in the context of asset administration shells [2] or Industry 4.0 components. From our point of view, digital twins will become a major topic for research over the coming years because they are not single objects or monolithic data models, but include different aspects of digital representations, functionalities, models, interfaces etc. From a manufacturing and engineering perspective, it is evident that digital twins require and cover a number of different aspects, such as

- self-description using unique attributes and parameters describing configuration data, e.g. for auto-identification, to connect machines and components easily to MES and other Industrial IoT-solutions [3].

- description of skills, including parts of the control code with the result that an assembly of components and their respective control logic elements fit into a finally running control program. This creates a PLUGandWORK environment where new components can be plugged in at runtime and integrated automatically on a functional level [4].

- models of the correct runtime behavior of a machine, a line or an entire manufacturing shop, based on learned data from machine learning.

- an extremely wide range of offline- and online-simulations, such as finite element simulations, virtual commissioning or physics simulations in which the manufactured goods interact with the machine kinematics. Ideally, the various simulation models should be able to interact in order to generate an integrated simulation model. Up until now, the digital twin has been used primarily in the context of simulation; as we point out here, this definition is much too narrow.

- a digital factory describing machines and other manufacturing resources, buildings and utilities. A building information model (BIM) might also be part of a digital twin as long as it contains relevant information, e.g. topology. The concept of digital factories already has a long history and is described by well-known standards, such as VDI 4499.

- services that a cyber-physical component offers to its users.

- IT security, access rights, handling of certificates, version management and compatibility checks of different versions of digital twins [5].

Digital twins are essential for Industry 4.0 and the digitization of manufacturing. Their content is key during all stages of the life cycle and within different types of platforms and tools, from engineering to after sales services. The following use cases already show the potential benefits, e.g. for optimizing products and processes almost during runtime:

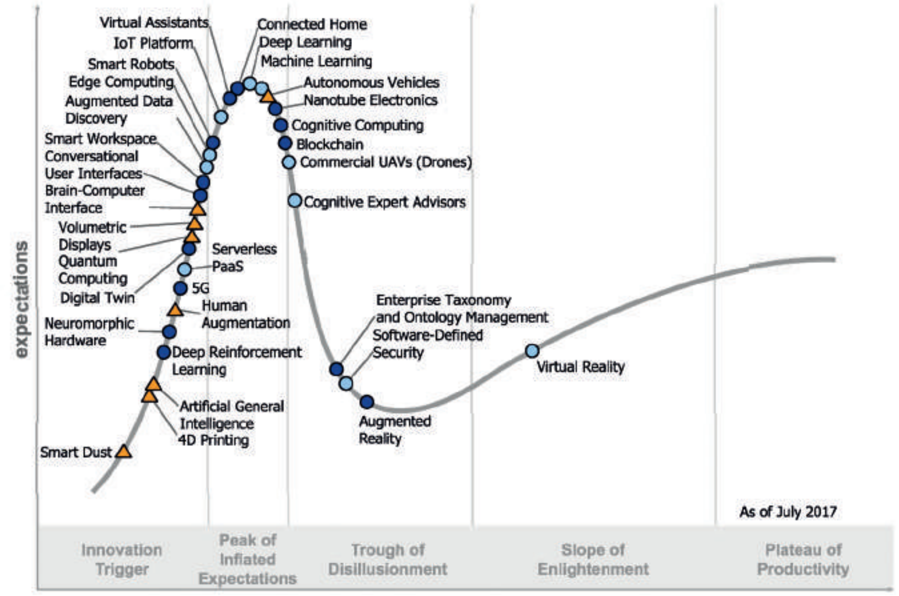


Figure 1: Gartner Hype Cycle for Emerging Technologies 2017.

1. The automation supplier WAGO has developed an approach called DIMA (decentralized intelligence for modular equipment) which allows modules from different vendors to be integrated into a final production system. At its core is the Module Type Package (MTP), a kind of self-description of the modules. The MTP can be accessed through an interface and contains communication parameters, functional production services that the module offers to the entire production system and information for the production monitoring system.

2. Components from FESTO are described as AutomationML models and include geometry, kinematics and software. They also refer e.g. to EPLAN schematic services, which are FESTO-built macro libraries for EPLAN Electric P8, V2. The components also store data from the application and from operations, pre-process the data according to VDMA 24582 in CODESYS V3 and transfer this information to a cloud.

3. Every HOMAG machine for manufacturing wooden workpieces has its own asset administration shell including a proprietary XML-description and an OPC UA-communication. Homag offers machine-related services, e.g. the diagnosis system woodScout. This includes integrated machine documentation via a connector from the Tapio cloud, which is owned by Homag and based on Microsoft Azure. Homag's customer Nobilia, a producer of kitchen furniture, uses Homag digital twins to demonstrate a virtual, customer-specific production system for lot size 1.

These initial examples clearly show that the application of digital twins will be very specific and always unique to the use case. However, it must also be possible to integrate the different part models of the digital twins easily based on their unique description.

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# DIGITAL TWINS FOR INDUSTRIAL ALARM MANAGEMENT

Digital twins are based on physical and functional information about components, products and systems which are necessary for production processes in each phase of the life cycle. One key aspect of a digital twin are the simulation models that extend data already available in different life cycle phases, such as design, engineering, operation, and service [1]. This article describes the application of a digital twin in one use case from the operation phase of an automated Production System (aPS): industrial alarm management.

The concept presented in this article was developed in the project "Innovative Modeling Approaches for Production Systems to Increase Validatable Efficiency" (IMPROVE). IMPROVE is sponsored by the European Union and focuses on virtual Factories of the Future (vFoF). Data-driven and model-based digital twins are part of a holistic solution for Self-X technologies, including diagnosis and optimization of industrial components, machines and plants [2]. Self-X technologies help to increase efficiency, reduce the frequency of failures and lower running costs. Fraunhofer IOSB-INA participates in IMPROVE with Ostwestfalen-Lippe University of Applied Sciences and 11 other partners from academia, industry, and software development.

One of the main use cases in IMPROVE is intelligent alarm management which focuses on analyzing alarms and warnings generated during plant operation. Unfortunately, many alarms that are displayed to the operator are either redundant alarms or nuisance alarms, such as chattering or lingering alarms. Eventually, the number of alarms becomes so high that it overwhelms the machine operator.

## ALARM FLOOD PROBLEM

Alarm flooding is a persistent problem in industrial plant operation [4]. It occurs when the frequency of alarm announcements becomes so high that the operator is overwhelmed and loses sight of how to solve the situation. In the worst case, that leads to critical alarms being overlooked and time-consuming searches for the root cause of the problem. This, in turn, may result in dangerous situations, significant downtime and even irreversible damage, such as the infamous explosion at a Texaco refinery which was found to be caused by a flood of alarms [3].

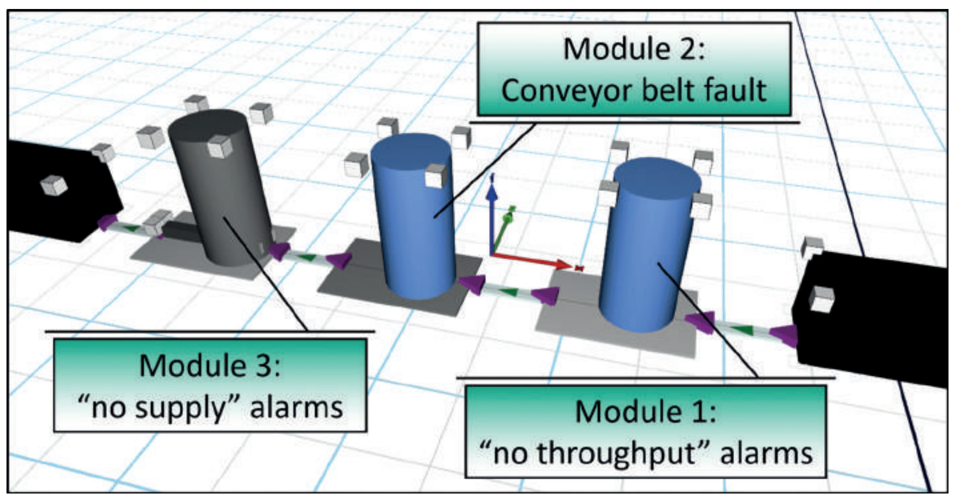


Fig. 1: An example of a simulation model of the SmartFactoryOWL Versatile Production System demonstrator behavior. A fault induced in Module 2 results in a production stop and an alarm flood.

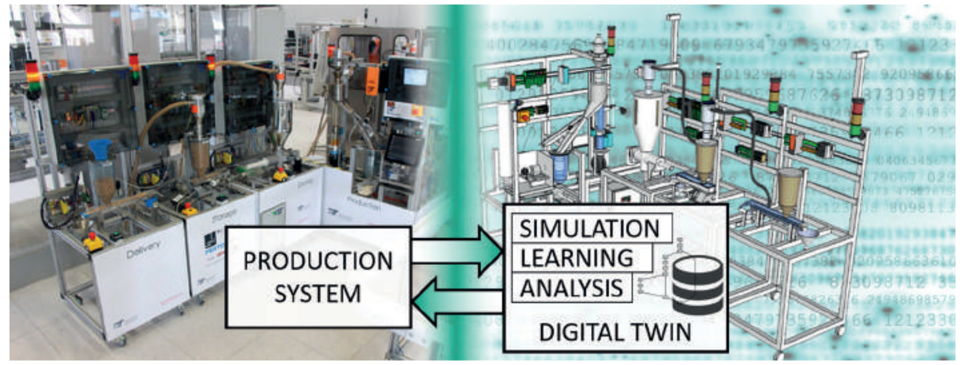


Fig. 2: The concept of a digital twin for industrial alarm management: a simulation model generates data used for case base construction, machine learning and analysis to support the operator of the production system.

The goal of an intelligent alarm management system is to avoid alarm flooding and support the operator if it nevertheless occurs. The main reason for alarm flooding is a flawed alarm system design. As revamping the alarm design of a running system is impossible and stopping production impractical, other solutions are required. Traditionally, alarm management has employed simple methods, such as basic signal and alarm filtering to remove alarms before they are displayed to the operator, or giving operators the option of shelving alarms they consider irrelevant or redundant. For anything more advanced than traditional methods, a deep understanding of the system – expert knowledge – is needed. This is either very difficult or too time consuming to obtain. Now, the rise of machine learning and data-driven computational intelligence allows us to consider more complex and intelligent approaches to alarm flooding – by utilizing a digital twin of the system. Intelligent approaches allow us to either reduce the number of alarms or assist the operator in identifying the root cause.

## ALARM MANAGEMENT USING A DIGITAL TWIN

In IMPROVE, the basis for the implementation of a digital twin for industrial alarm management is a simulation environment that uses the PhysX engine for discrete event simulation. The PhysX engine controls the behavior of basic physical elements, for example tracks and conveyor belts or discrete loads representing manufactured goods. The design of the simulation model is enriched with the custom behavior of production units and sensors, definitions for raising alarms based on sensor values as well as a flood detection system. Discrete event simulation allows the user to greatly speed up the flow of time and observe long-term behavior of the plant model – and record the data. Inducing failures in specific modules allows us to collect a case base of alarm flood samples with semantic annotations. Fig. 1 shows an example of such a model, simulating a scenario where a fault induced in one module triggers an alarm flood. A simulated case base is a valuable tool which can be analyzed and the results applied to the real plant. The raw case base is itself a model of faulty behavior in the plant and can be analyzed using data mining approaches in order to gain insights into recurring problems in the plant. Moreover, it can be used to directly support the operator during an alarm flood in a running plant. Machine learning approaches can find similar, previously seen and annotated cases to suggest possible solutions to the operator [5]. Furthermore, a case base can also be used to learn a variety of further models – such as causality models based on Bayesian networks or Markov chains. Such models shed light on dependencies between alarms, which can be used to reduce the number of alarms displayed.

The combination of the simulation model with the embedded behavior and the model-learning and analysis approaches constitutes the digital twin (illustrated in Fig. 2). In the context of industrial alarm management, the digital twin is used to construct a database of alarm floods. This is useful for analyzing the overall behavior of the alarm system as well as supporting the operator during plant operation.

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# SECURE INDUSTRY 4.0 COMMUNICATION FOR COMPRESSED AIR SYSTEMS BASED ON OPC UA AND IEC 62443

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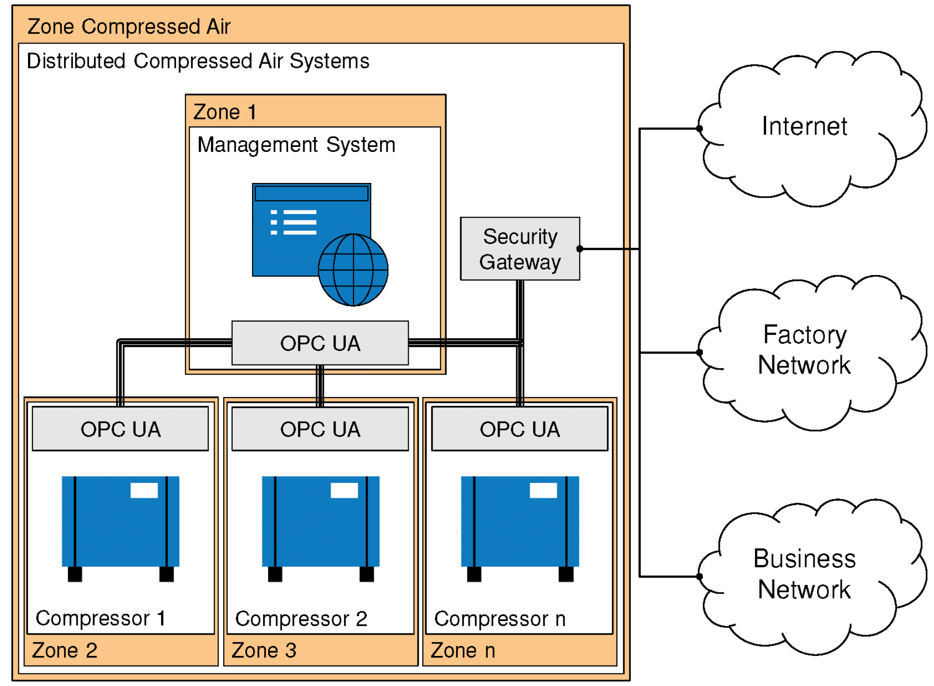
Compressed air systems are a common element of cyber-physical production environments. Due to their widespread use, for example in conveyor belt transport systems, there is great potential to reduce the engineering work required for configuration. Fraunhofer IOSB-INA is working in partnership with BOGE – an industrial manufacturer of compressed air systems located in Bielefeld – to simplify the commissioning of these assemblies. The challenge of commissioning a compressed air system lies in the configuration of communication and performance parameters, such as pressure and flow rates. The solution was developed by applying the Plug-and-Work mechanism and implementing secure Industry 4.0 communication in accordance with the IEC 62443 standard. The resulting transfer project entitled "Automatic Configuration of Distributed Compressed Air Systems" was funded by the "Intelligent Technical Systems Ostwestfalen-Lippe" (it's OWL) technology network with the goal of transferring technologies and solutions compliant with Industry 4.0 to industrial companies.

A compressed air system consists of a central controller, distributed compressors, and a communication connection. OPC UA middleware was chosen to connect the compressed air management system (the central controller) with the compressors. OPC UA enables a semantic description of components using an information model which describes the functions and parameters of a compressor. Fraunhofer IOSB-INA developed an information model for BOGE compressors based on the OPC UA device specification. The information model was deployed to an OPC UA server running on a single board computer to allow easy retrofitting of existing compressors. The OPC UA discovery mechanism allows the compressed air management system to detect connected compressors and automatically integrate them into a consistent compressed air system.

Secure Intelligent Networking and Plug-and-Work for compressed air systems can be seen in the SmartFactoryOWL.




Secure Industry 4.0 communication is implemented according to the IEC 62443 standard by applying security concepts based on zones and communication conduits.

The integration of OPC UA into the compressed air system of SmartFactoryOWL was performed in accordance with the IEC 62443 standard for implementing secure Industry 4.0 communication. The IEC standard defines the aspects of secure Industry 4.0 communication and describes the requirements for IT security in industrial automation and control systems, in particular the concepts of isolated zones and secure communication conduits. Accordingly, the compressed air management system and the compressor are each defined as a separate isolated zone. The individual zones of the compressed air system are, in turn, part of a higher-level zone. A security gateway permits secure communication between the compressed air network and the other networks of SmartFactoryOWL. Communication between the zones takes place exclusively over OPC UA. The solution is secured by encryption, authentication and authorized user groups according to the principle of least privilege.

Integration of the Plug-and-Work mechanism into the research factory SmartFactoryOWL successfully applied the concept of secure Industry 4.0 communication to existing compressed air systems. This solution concept, developed by Fraunhofer IOSB-INA, has helped BOGE automatically and securely to connect compressors to the compressed air management system. It reduces the time, effort and costs involved in commissioning and configuration.

"The technology transfer from Fraunhofer IOSB-INA in the field of automatic configuration and intelligent networking systems, raised our technology level to the state-of-the-art within a very short time period. In the short term, we will launch appropriate products for new applications. Exploiting innovations in this simple way will sustainably strengthen and expand our region OWL", concludes Peter Boldt, Head of Development at BOGE.

For more information go to:
www.cybersecurity-owl.de

Reference:

[1] Otto, J.; Böttcher, B.; Niggemann, O.: Plug-and-Produce: Semantic Module Profile; In: Dagstuhl-Workshop MBEES: Modellbasierte Entwicklung eingebetteter Systeme IV; April 2013

[2] Dürkop, L.; Trsek, H.; Otto, J.; Jasperneite, J.: A field level architecture for reconfigurable real-time automation systems. In: 10th IEEE Workshop on Factory Communication Systems, Toulouse, Mai 2014

[3] Otto, J.; Schriegel, S.; Niggemann, O.: Eine Taxonomie für Plug & Produce. In: Automation 2015, Baden-Baden, Jun. 2015

[4] Otto, J.; Niggemann, O.: Automatic Parameterization of Automation Software for Plug-and-Produce. In: AAAI-15 Workshop on Algorithm Configuration (AlgoConf), Austin, Texas, Jan. 2015

[5] Otto, J.; Vogel-Heuser, B.; Niggemann, O.: Automatic Parameter Estimation for Reusable Software Components of Modular and Reconfigurable Cyber-Physical Production Systems in the Domain of Discrete Manufacturing. In: IEEE Transactions on Industrial Informatics Volume 14, Jan. 2018

[6] IEC 62443-1-1 Industrial communication networks – Network and system security –Terminology, concepts and models; Jul. 2009

[7] IEC 62443-3-2 Security Risk Assessment, System Partitioning and Security Levels; IEC 62443 Security for industrial automation and control systems; May 2017.

# FLEXIBLE REAL-TIME COMMUNICATION IN AUTOMATION WITH OPC UA PUBLISH/SUBSCRIBE AND TIME SENSITIVE NETWORKING

Multi-Vendor TSN & Open Source OPC UA

open62541

OSADL | kalycito Your R&D Partner | Fraunhofer IOSB

Fraunhofer IOSB has developed the world's first open-source implementation of OPC UA publish/subscribe and demonstrated its real-time capability in combination with Time Sensitive Networking (TSN). The team at Fraunhofer IOSB showed that a real-time capable publisher and a non-real-time standard OPC UA server can coexist in the same device without losing real-time capabilities through access to a shared information model.

Until today, fieldbuses have been the dominant technology for real-time communication in automation systems. A fieldbus defines specific telegram formats for cyclic data exchange. OPC UA is not a fieldbus, but a client/server protocol based on TCP/IP that defines service calls for the interaction with a server-side information model over the network. The new part 14 of the OPC UA specification defines an enhancement of OPC UA for communication based on the publish/subscribe communication paradigm. In publish/subscribe, subscribers registers for a subject (also called a topic or queue) and receives all messages that are published on that subject. So a published message is distributed to a potentially large number of subscribers. Part 14 of the OPC UA specification refers to broker-based message distribution according to the IEC standards AMQP and MQTT. It additionally defines a custom UDP-based distribution protocol, called UADP, based on the multicast mechanisms of the IP standards. With multicast, the subscriber registers in a group represented by an IP address in a special range. Packets sent to this address are forwarded to all members of the group. Thus the major part of the complexity of the publish/subscribe mechanism is delegated to the existing network infrastructure (router, switches etc.). The content of the published messages is defined by a so-called DataSet: a collection of current values from selected elements of an OPC UA information model. In that regard, OPC UA publish/subscribe returns to the definition of telegram formats. But in contrast, the DataSet can be flexibly configured at runtime and this definition can be looked up in the server to understand the semantic meaning of values according to their origin in an OPC UA information model.

Within the IEEE 802.1 standards series, the enhancement of Ethernet with real-time communication under the name of Time Sensitive Networking (TSN) has been pushed forward during recent years. Some parts of the future TSN standard have already been adopted, such as clock synchronization of the participants in IEEE 802.1AS and the reservation of transfer capacity via time slots in IEEE 802.1Qbv. This realizes real-time communication in parallel to normal Ethernet operation. One disadvantage of OPC UA has been the lack of real-time guarantees due to the use of TCP/IP as a "best effort" transport layer. Integration with TSN makes OPC UA publish/subscribe an ideal companion to the client/server interaction with additional end-to-end real-time guarantees. Together with the Open Source in Automation Development Lab (OSADL) and Kalycito Infotech, a systems integrator for embedded applications, Fraunhofer IOSB has launched a project to develop OPC UA publish/subscribe. This effort is based on the open62541 open source implementation of the OPC UA standard IEC 62541 (https://open62541.org). open62541 is developed in the C language and can be used for resource-constrained embedded applications. Five companies from the automation industry, all members of OSADL, are jointly funding the project.

The first outcome of the project was a demonstrator for Embedded World 2018. The integration with current TSN hardware depends on vendor-specific interfaces and configuration tools. Nevertheless, large parts of the OPC UA publish/subscribe implementation is reusable and has been folded back into the open62541 project.

The key feature of the publish/subscribe implementation by Fraunhofer IOSB is the connection between the real-time capable publisher and the non-real-time normal OPC UA server. Any activity in the normal server must not delay the real-time publisher although both interact with the same information model. Fraunhofer IOSB's implementation realizes this using a special representation for the OPC UA information model: every node in the information model is immutable and cannot be modified. It is only possible to replace the entire node with a modified copy. This replacement uses atomic operations, whereby parallel access to the information model is possible without the use of semaphores. A time-controlled hardware interrupt can then trigger the generation of publish messages and the information model cannot be in an inconsistent state at the time of the interrupt. Real-time operations for TSN and the flexible best-effort operations can therefore co-exist in one device. This is an important basis for the main idea of Industry 4.0: to flexibly connect automation systems, to perform additional configuration at runtime and to integrate runtime control with higher-order functionality and services.


Demonstrator

Reference:

[1] OpenMOS Project Deliverable:
Assessment of Current Service Bus Technologies.
https://www.openmos.eu/documents/11/D3.2_-_Assessment_of_Current_Service_Bus_Technologies.pdf

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# SEMANTIC EDGE PROCESSING

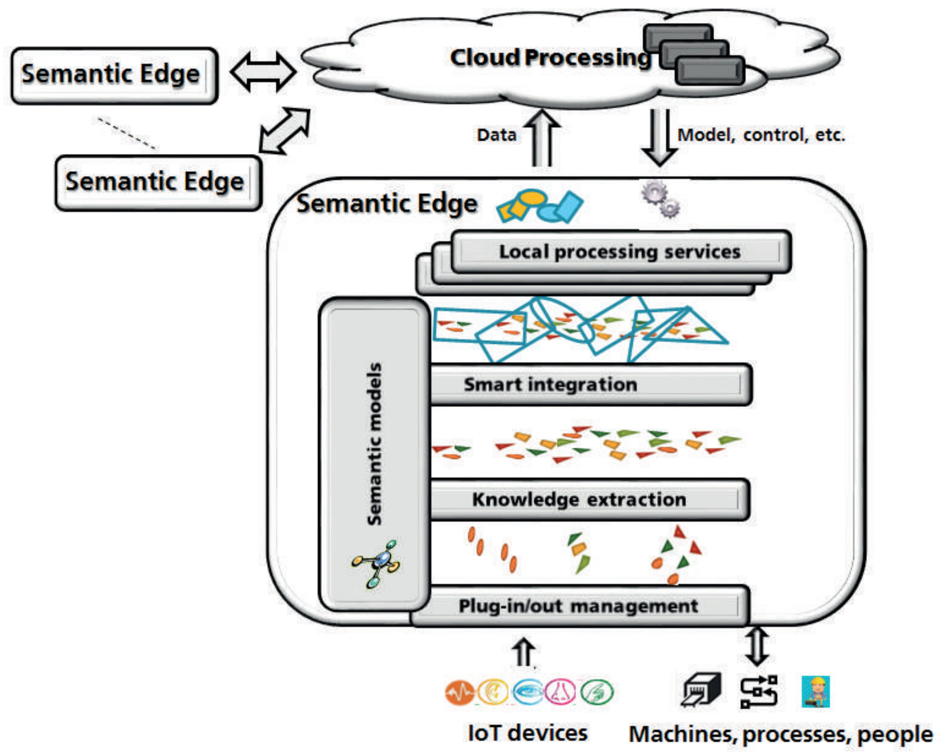


Fig. 1: Semantic Edge to intelligently collect, pre-process, aggregate, and analyze data close to the data sources.

The Industrial Internet of Things (IIoT) is the use of the Internet of Things (IoT) in the industrial domain with the goal of monitoring and controlling production processes. The manufacturing sector is expected to be one of the top adopters of IoT technologies [1], [2]. Leveraging the power of advanced sensing technologies, applications, such as remote monitoring, anomaly detection, diagnosis, and control of processes and assets have already gained rapid popularity in manufacturing industries. While huge progress has been made on making assets "smarter" and production more efficient over recent years, the full potential of the IIoT has not yet been exploited sufficiently.

The main reasons are:

- the available bandwidth for the data transmission is usually not sufficient for the vast amount and frequency of data created by IIoT devices;
- the manufacturing domain has very demanding ultra-low latency requirements for processing data;
- connectivity (and consequently the availability of services) is hard to guarantee;
- a large class of IIoT applications do not meet the security requirements.

To help manufacturing companies take full advantage of the IIoT, we have developed methods and tools to intelligently handle the IoT sensor data and process data at the edge of the network and deliver faster insights [3]. The key innovation is in IoTization through dynamic, multi-modal, smart data gathering, integration and processing based on semantic technologies.

As shown on Fig. 1, we do not focus purely on asset data; we take into account data from the environment in which the asset operates and the associated processes and resources that interact with the asset. We consider structured data (e.g. sensor data), semi-structured data (e.g. inspection reports) and unstructured data (e.g. corrosion images). The semantic edge is used to communicate with the industrial asset, perform local processing (e.g. edge analytics) and transfer pre-processed data to the cloud. It can be deployed either on a machine or on a gateway, depending on the complexity and resource-consumption of the services to be used.

Looking at the figure from bottom to top, the components are organized in layers (with push connectors) starting from data sources at the bottom to the communication services that support bidirectional communications between the edge services and cloud services. The vertical layer services are realized by the semantic models, which ensure a common, shared understanding is achieved across the existing OT and IT systems, edge services and various human roles.

The semantic edge is structured in the following sub-layers:

- the plug-in/out management layer enables on demand plug-in/out based on out-of-the-box connectivity;
- the knowledge extraction layer creates machine-understandable representation of the raw sensor data;
- the smart integration layer ensures data fusion in real-time near to the data sources by dealing with both syntactic heterogeneity and semantic heterogeneity;
- the intelligent service layer comprises the many services for building advanced applications suitable for the edge.

Fig. 2 shows the real-time data analytics service which correlates sensor data and/or derived data into more meaningful information for making better and faster decisions. It searches for patterns in a continuous stream of incoming events in order to detect situations with minimal delay (i.e. look for a combination of certain types of events to create a higher-level business event). The service consists of:

- an app for managing sensors and patterns, creating patterns using the drag and drop visual interface by combing events and pattern operators (e.g. filtering, aggregation, time-window, etc.), deploying patterns (e.g. on Raspberry Pi) and displaying notifications;
- a set of components based on the WSO2 Siddhi engine for embedded systems for discovering patterns in real-time, sending notifications or even performing actions (e.g. switch on/off a sensor).

The proposed approach is driven by real industrial use cases and includes a proof-of-concept demonstration for validation with real-time data.

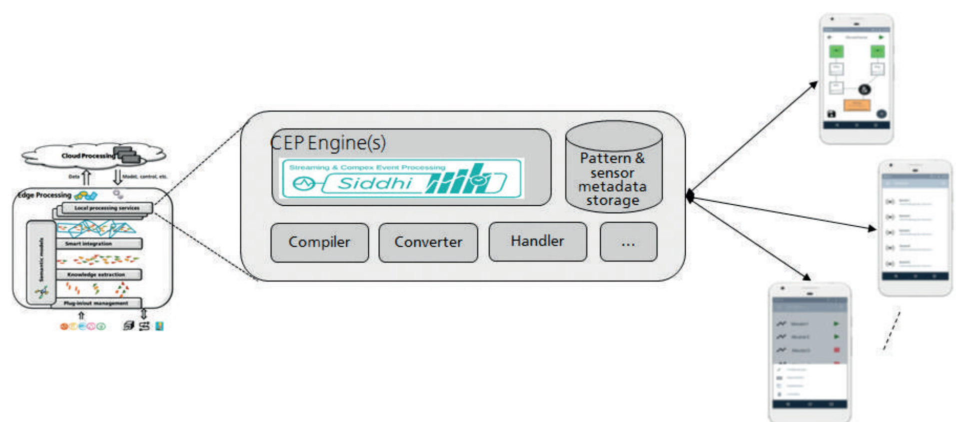


Fig. 2: Real-time data analytics by "moving" analytics to the edge.


Reference:

[1] https://ww2.frost.com/news/press-releases/innovations-enabled-industrial-iot-accelerate-shift-manufacturing-40/

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[3] IoT edge analytics is transforming manufacturing, https://www.ibm.com/blogs/internet-of-things/smart-manufacturing-edge-analytics/



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Themes

# CLOUD-BASED DATA ANALYSIS AND CONDITION MONITORING PLATFORM FOR INDUSTRIAL PRODUCTION PLANTS

Modern industrial plants usually incorporate a large number of sensors and are characterized by increased interconnectivity between their various process units. Moreover, small lot sizes and the demands of making high quality products mean that manufacturing plants are increasingly subject to modifications. Before every change, the operating staff have to adapt process parameters. As a result, they become more and more challenged by the process control and supervision systems.

In terms of process supervision, this means that operators need to set new thresholds for several sensors and potentially adapt them whenever a product changeover is performed. Since this work is time-consuming and requires a large amount of expert knowledge, the use of machine learning algorithms offers a promising alternative. Using this method, the system can learn a model which represents the normal state of a process. Next, this model is compared with the current process data. If the measurements diverge significantly from the model, this may be evidence of abnormal process behavior and the operating engineer needs to be informed. However, widespread utilization of machine learning algorithms has not yet been adopted. One reason is that it not only requires an operating engineer but also a data scientist with the expertise to train, parametrize and update the learned model at regular intervals.

## INTELLIGENT DATA ANALYSIS THROUGH CLOUD SERVICE

Most facilities that want to take advantage of machine learning for their process units and productions plants, do not have the staffing level required to employ data scientists. Fraunhofer IOSB now offers a solution to this problem – a cloud-based data analysis and condition monitoring platform capable of analyzing production data on behalf of such facilities [1]. The complete data analysis platform can be hosted by IOSB or in-house.

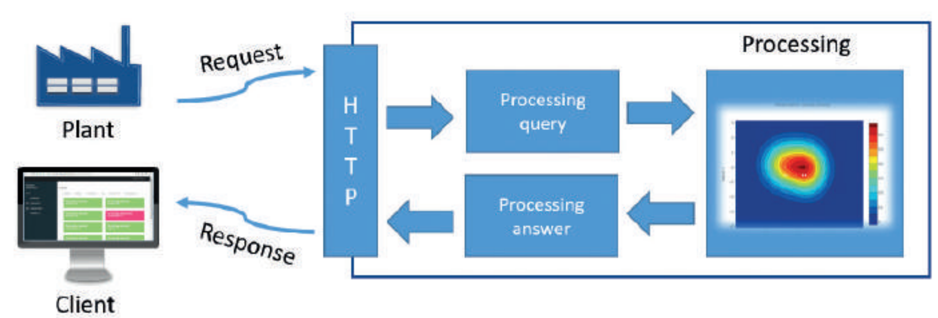


Fig. 1: I4.0 Test Lab at the Fraunhofer IOSB used for the development and testing of new algorithms for the evaluation of production data.

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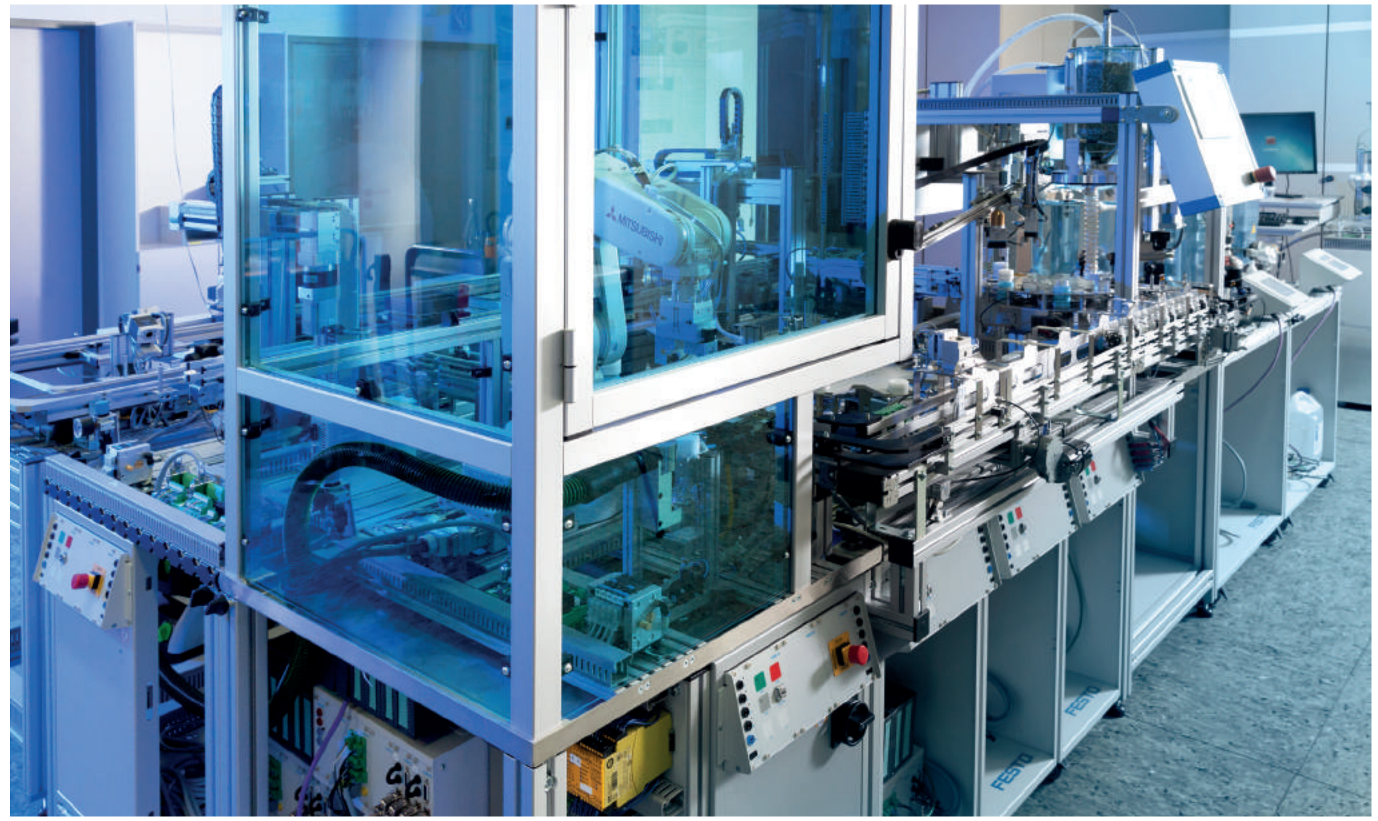

Fig. 2: Measurement data are uploaded to the cloud and processes using ML algorithms. Results are written back to plant or sent to a web client for visualization.

Fig. 2 outlines the approach. Facilities can send a request as streaming data or cyclically upload their measurements. For streaming data this can be done through standard protocols, such as OPC-UA [2] or REST, but it is also possible to develop a custom interface since internally the platform follows a plug-in based architecture.

For the response, there are two possible ways for the operator to obtain the results. First, they can be written back to the local management system. This demands that the facility provides, e.g. OPC-UA nodes for the machine learner. Second, they can be visualized using a password protected web application. Currently, the web application includes a dashboard, the visualization of a process map with state trajectory and access to historic results from the machine learning algorithms. However, the web client can be adapted to the specific needs of the end user.

## SUCCESSFUL TESTS FOR MONITORING DRINKING WATER FACILITIES AND QUALITY ASSURANCE IN POLYSTYRENE PANELS

The developed platform has been successfully tested at the IOSB Test Lab (Fig. 1) in monitoring drinking water facilities [3] and quality assurance in polystyrene panel production. In the former application, the data are uploaded hourly as .csv files and the results provided within the web-interface. In the latter, the data  are uploaded from the complete production batch and the panel quality assurance results provided as a report

Reference:

[1] Kühnert C.; Montalvo I.: A Generic Data Fusion and Analysis Platform for Cyber-Physical Systems, Machine Learning for Cyber-Physical Systems, 2016

[2] Schleipen, M; Kühnert C.; Okon M.; Henßen R.; Bischoff, T.: MoMo – Mobile Monitoring und smarte Datenanalyse basierend auf offenen Standards, VDI Automation 2015

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# ENGINEERING OF DIGITAL TWINS

## MOTIVATION

Representing real world objects as digital models has been a central topic of computer science for many years. System modelers have always been interested in finding ways to represent features and properties of physical objects digitally in an adequate and efficient way for a given task. However, in order to reduce the complexity and due to the limitations of IT devices w.r.t. memory consumption and processing capacity, the digital views have always been quite tightly focused. In automation technology, this means that the digital model of a machine in a production control system, in addition to identification data, comprises only those machine status and operational data which are relevant for an operator. Engineering data describing type and geometry are typically not accessible from the production control system. Today, these distinct representations, usually stored and provided by different, mostly incompatible IT systems, hinder integrated modeling and simulation concepts for digital factory components as well as integrated industrial analytics.

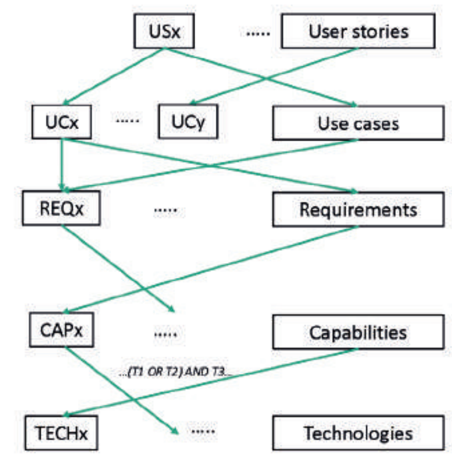
The concept of the "digital twin" is about to change this. It conveys the idea that digital representations should possess many of essential properties of their real-world counterparts. Moreover, it expresses the expectation that the digital representation should be synchronized, as far as possible, with the status of the real-world object. Ideally, it should be an exact image of all the properties and functions of the physical component (e.g. a robot arm or a pressure sensor), synchronized in (near) real-time throughout its life. Consequently, an operation upon the digital twin should instantly affect the physical component and vice versa. Today, embedded sensors and sensor data processing close to the device (edge computing), the Industrial Internet of Things (IIoT) for ubiquitous data transmission (machine-to-machine – M2M) as well as cost-efficient and scalable data storage make this type of synchronization possible.

## CONCEPT OF DIGITAL TWINS

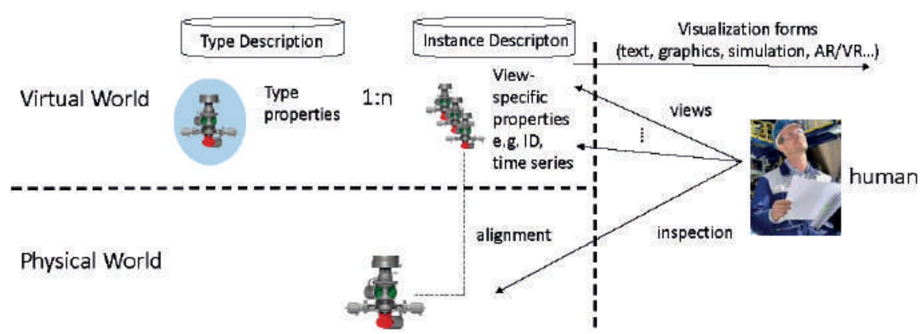
However, the term digital twin is misleading. Although biological twins exhibit many genetic matches and start from a common environment, they evolve and socialize largely autonomously and independently of each other, at least with increasing age. Conversely, the "socialization" and lifetime of a digital twin in a digital factory is basically independent of that of its real-world counterpart. In design and engineering departments, digital representations are created in virtual environments which are becoming ever closer to reality. A robot arm may be simulated in its cooperation with other robot arms or humans and optimized in its behavior before the physical robot arm is even produced and installed. In the virtual world, time may be wound back and forth as required. This enables analysts to evaluate past situations and simulate future situations by means of prognostic models. Long after the life of the physical object has come to an end, e.g. due to wear or dismantling, the virtual representation may still be stored for documentation purposes. Despite the enormous progress made in technology, today's digital twins are only capable of encompassing partial aspects of the real object. In Industry 4.0, these meta-data sets are logically contained in the so-called asset administration shell (AAS). The AAS distinguishes between sub-models that are determined by application domains, industrial sectors and their standards, and views that are defined by the functional and informational shell of those properties that are required by the intended use cases.

## ENGINEERING METHODOLOGY OF IOSB

Hence, when considering the engineering of digital twins, it is important to know which properties are required and how to map them to the sub-models. Fraunhofer IOSB provides a methodology known as SERVUS (service-oriented design of information systems based upon use case specifications) which systematically supports the information system analyst and designer in this task. Validated in industrial project situations, it allows an analyst to specify and document use cases as semi-structured tables, break them down into requirements and map them in an agile manner to capabilities and technologies of existing and emerging IIoT platforms. These analysis and design activities are supported by a Platform Engineering Information System (PEIS).PEIS helps to mediate between the possibly conflicting demands of users, product managers, software engineers and technology experts. A methodology of this type is indispensable for engineering digital twins as they need a deployment and runtime environment which is service-oriented and based upon open standard technologies.




SERVUS Meta-model




Concept of a digital twin (simplified)

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# SMART FACTORY WEB


## MOTIVATION

The Korean Institute KETI and Fraunhofer IOSB have launched a project financed by the Korean Ministry of Trade, Industry & Energy (MOTIE). Based on Industrial Internet of Things (IIoT) concepts, we are investigating integrated architectures and technologies for a web of distributed smart factories.

The Smart Factory Web, an approved Testbed of the Industrial Internet Consortium (IIC), aims to network a web of smart factories to improve order fulfillment by aligning capacity across production sites with flexible adaptation of production capabilities and sharing of resources, assets and inventory. The main usage scenario is accordingly "order driven adaptive production". Factory owners can flexibly adapt production processes and value chains to new customer requirements.

The Smart Factory Web Testbed simultaneously targets Korea's "Manufacturing Innovation 3.0" and Germany's "Industry 4.0" [1] initiatives. Both strategies involve adaptable factories that offer fully automated production capabilities and capacities in highly modularized production facilities that can be adapted and optimized on an order-by-order basis.

## IMPLEMENTATION ARCHITECTURE

The architecture of the Smart Factory Web applies the conceptual views and specifications of the IIC in its Industrial Internet Reference Architecture (IIRA). The model factories of KETI in Pangyo and Ansan (South Korea) and of Fraunhofer IOSB in Karlsruhe and Lemgo (Germany) are linked via the Smart Factory Web. The German model factories are also members of the Industrie 4.0 Labs Network and thus help to promote the alignment of the Reference Architecture Model (RAMI4.0) of Industrie 4.0 with IIRA.

The Smart Factory Web manages the registration of and search for factories in the Smart Factory Web. Assets are modelled in terms of their capabilities and properties. Cockpit applications visualize selected factory data.

KETI has implemented an interoperable network environment via OPC UA in both the Pangyo and Ansan model factories. This is engineered using AutomationML. By adopting a data conversion module from OPC UA to oneM2M, which is a standard for machine to machine communications, further devices and applications can be integrated easily into the testbed.

The Korean and German model factories will connect to the Microsoft Azure cloud platform to show factory data in real-time. The shop floor data to be transferred to the cloud is aggregated on an OPC UA aggregation server with the help of an information model defined in AutomationML and CEP (Complex Event Processing) to extract actionable events from patterns in the data. The AutomationML model is also used to configure the data visualization on the Azure cloud. KETI's Ansan model factory is also connected to the Siemens' Mindsphere platform to demonstrate product independence.

## STANDARDS

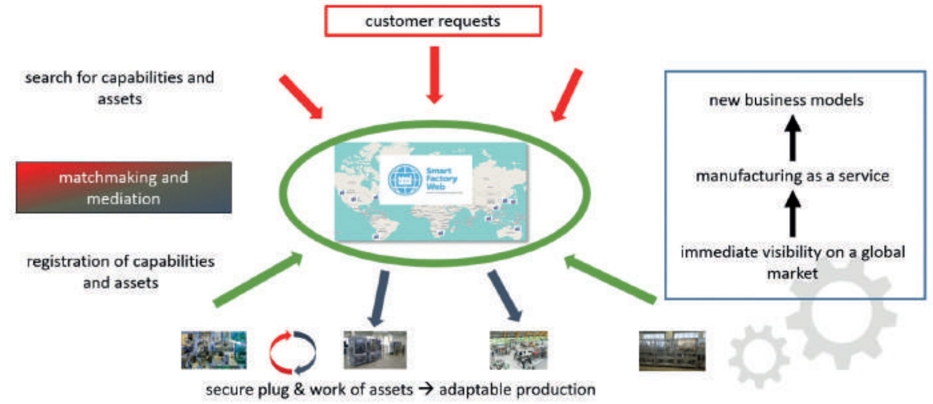
The standards AutomationML (IEC 62714) and OPC UA (IEC 62541), complemented by the companion specification "OPC Unified Architecture for AutomationML", play a key role. The combination of these standards reduces the manual engineering effort required for production adaptation and exchange of information in factories.

## OUTLOOK

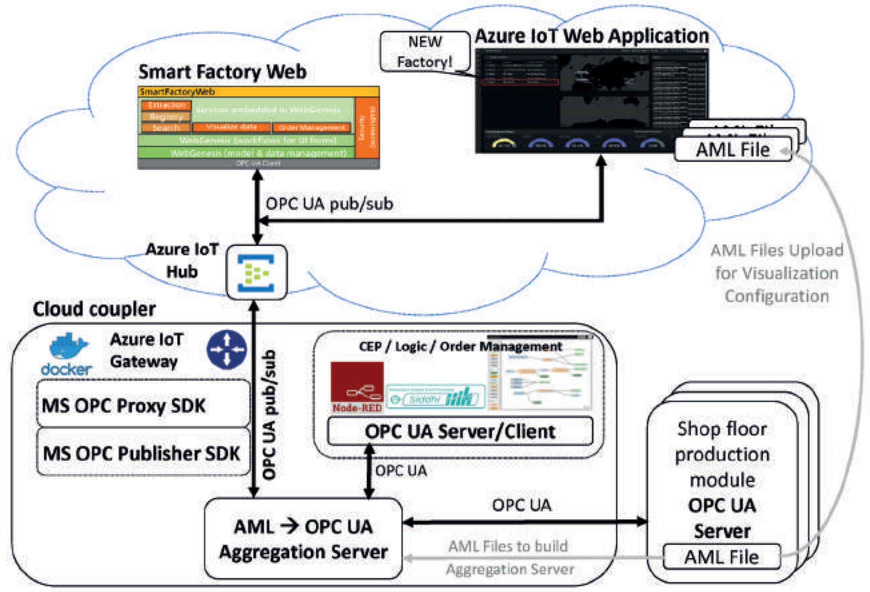
The collaboration between KETI and IOSB advances the international usage of standards and architecture patterns for IIoT systems. Benefits are expected for data and service integration and advanced plug &work, both fundamental for smart factories. Both research organizations conduct training, consultancy and development projects for industrial clients.

The two organizations plan to integrate further smart factories and applications into the Smart Factory Web.

For more information go to:
www.smartfactoryweb.com.




Towards a Marketplace for Manufacturing.




Integrating Factory into Smart Factory Web and example cloud.

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2. Ministry of Trade, Industry and Energy (MOTIE), The Industrial Innovation Movement 3.0, 29.12.2014
http://english.motie.go.kr

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