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Symposium on Industry 4.0: Powering Smart Manufacturing – the TU9 Alliance of German Institutes of Technology

26 October 2016 | Tokyo, Japan

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Symposium on Industry 4.0: Powering Smart Manufacturing – the TU9 Alliance of German Institutes of Technology

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Industry 4.0 is synonymous with the next stage of digitization of the manufacturing sector. The fusion of ICT and manufacturing technologies has the potential to transform entire systems of production. Real-time optimized and self-organized supply chain networks across corporate boundaries will lead to long-term gains in efficiency and productivity and eventually open new markets.

Industry 4.0 offers multiple approaches for realizing potential related to the transition from computer-integrated-manufacturing to "smart manufacturing". Based on the criteria functionality, efficiency, functional safety and cyber security, Industry 4.0 seeks to identify and link relevant technologies for "smart factories".

The joint Symposium of the German Research and Innovation Forum Tokyo and the TU9 Alliance of German Institutes of Technology focused on the progress that leading German universities have made in implementing Industry 4.0 and provided a platform for German and Japanese experts to meet and exchange views on cutting-edge technology as well as the current state of education and R&D in the field of "smart manufacturing".

Representatives from academia and industry attended the symposium to deepen their understanding and exchange views on issues such as smart, connected products, digital infrastructure, integrated production systems and human-robot interaction.

We are pleased to present the Symposium's proceedings, which, we hope, will contribute to making its outcomes known to the wider academic community and the general public.

Professor Dr Horst Hippler
President, German Rectors' Conference

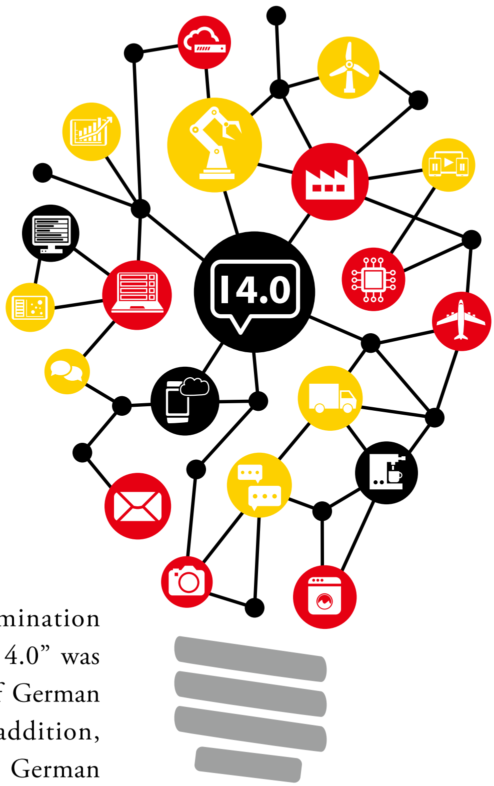
Professor Dr Hans-Jürgen Prömel
President, TU9 German Institutes of Technology

Overview of Industrie 4.0 in Germany

Reiner Anderl

Industrie 4.0 was initiated by the German high-tech strategy. The term Industrie 4.0 is a play on words consisting of 3 parts. First, "Industrie" indicates that this initiative is dedicated to industry. Second, the "4" stands for the 4th industrial revolution and aims at reaching a new level of industrial value chains covering the whole product lifecycle. Third, ".0" is a reference to internet technology and intends to create the association with Web 1.0, Web 2.0, Web 3.0, Web n.0 technology.

Industrie 4.0 aims to use technology to create new value-added chains covering the whole product lifecycle. The technological approach is based on the introduction of so-called Cyber-Physical Systems (CPS), which comprise modern control systems containing embedded systems equipped with a connectivity unit (for example an internet address). CPS's combine digital representations (cyber) with real parts, systems, products or production equipment (physical). The approach is to bi-directionally reference the digital and the real world. The CPS approach allows future products and production equipment to be interlinked and to communicate. The strategic target of Industrie 4.0 is therefore to enhance production flexibility as well as product configuration and adaptability and to contribute to enabling the individualization of products, produced at the cost of mass production.



To further develop Industrie 4.0 and its dissemination and utilization in industry, "Plattform Industrie 4.0" was founded. This organization is a joint initiative of German federal ministries, industry and academia. In addition, joint research programs have been set up by the German

Federal Ministry of Education and Research (BMBF). The German Federal Ministry of Economic Affairs and Energy (BMWi) has also funded programmes for transferring Industrie 4.0 to industry, in particular to small and medium-sized enterprises (SMEs). Furthermore, German state governments have also become aware of the importance of Industrie 4.0 and support the digital transformation of industry based on Industrie 4.0.

Through Industrie 4.0, new technological fundamentals have been developed and published. The major fundamental results comprise the "Reference Architecture Model Industrie 4.0" (abbreviated RAMI 4.0) and the so called "Industrie 4.0 component".
RAMI 4.0 defines the reference architecture consisting of three dimensions: the lifecycle and value stream, the hierarchy levels and the integration layers. RAMI 4.0 provides orientation for the development and the systematic application of Industrie 4.0 and also publishes consistent terminology.
The Industrie 4.0 component is an approach for enabling access to, for example, control units by integrating an administrative shell. The advantage of the Industrie 4.0 component concept is that you can manage component configuration, data transfer and access functionality depending on the complexity of the Industrie 4.0 component.
Resulting from the fundamental Industrie 4.0, approaches for various industrial application scenarios have been described. A subset of these application scenarios have been implemented in the so-called "Efficient Factory 4.0" at Technische Universität Darmstadt as industrial use cases. These use cases comprise:

- Workpieces, manufactured parts and manufacturing equipment used as information carriers,
- Improved value-added chains,
- Predictive maintenance,
- Condition and energy monitoring,
- Flexible and intelligent worker assistance
- IT-security, safety, privacy, knowledge and intellectual property protection.

To disseminate Industrie 4.0 to German industry, in particular to SMEs, competence centres have been established. The scope of Industrie 4.0 competence centres is to transfer Industrie 4.0 know-how to the industry, to develop advanced

Industrie 4.0 competences and to establish networks of excellence for promoting best practice implementations.

An important contribution to support the digital transformation based on Industrie 4.0 is provided by the Industrie 4.0 implementation guideline which was funded and published by VDMA (Verband Deutscher Maschinen- und Anlagenbau e. V.). This implementation guideline proposes so-called tool kits to identify the current performance of products and production of an enterprise and to develop a strategy for further improvement with respect to approaching Industrie 4.0 profiles.
Industrie 4.0 is a fascinating vision for strengthening industry´s competition profile. Industrial enterprises are required to intensively assess the options of an Industrie 4.0 implementation within the entire enterprise. In any case a decision has to be made about whether, and if so, how Industrie 4.0 should be introduced in the enterprise. Furthermore, management needs to be aware that the establishment of new business models has to be decided on.

Further reading:

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The Japanese Initiative
"Industrial Value Chain Platform for Connected Factories"
Yasuyuki Nishioka

The Industrial Value Chain Initiative (IVI), a Japan-based non-profit organization for connected manufacturing, is beginning to provide IVI platform reference specifications. IVI platforms are primarily for manufacturers who use their own data extracted from the factory. Field-level requirements in the factory will be built in bottom-up bases in accordance with IVI's scenario-making procedures. This talk presented how the IVI platform reference models act as a guide to retaining interoperability between the platform components. Concluding remarks suggested that the specification of the platform reference model can bring stakeholders – such as application vendors, device makers, tool vendors, infrastructure providers – to a connected manufacturing ecosystem in the future.

Robots and Humans in the Digital World
Sami Haddadin

Over decades, one of the primary goals of robotics research has been to enable robots for direct physical interaction and cooperation with humans and potentially unknown environments. The community's overall vision is to make

robots a commodity by putting the human at the centre of the robot design. This design paradigm allows the seamless connection of efficiency, digitalization and intelligent automation in order to achieve an optimum user experience. It was outlined how human-centred robot design, control and planning may let connected robots for humans become a commodity in our near-future society, and has already led to the first commercial interconnected systems capable of interaction. The primary objective of a robot's action around humans is to ensure that "a robot may not injure a human being or (through inaction) allow a human being to come to harm". For this, compliant and force/impedance controlled ultra-lightweight systems capable of full collision handling serve as the "safe robot body", enabling high- performance human assistance over a wide variety of application domains. In this context, the concepts behind a new generation of joint torque controlled soft-robots that are fully connected to the cloud and can be programmed by anyone via their APP framework were outlined. Besides being extremely cost-efficient and having high performance in both accuracy and force control, the presumably first robot that actually builds itself – perfectly suited for mass production – was presented.

A Modular and Low-Cost Infrastructure for Industrie 4.0 Applications – Linking Real-Time Data to the Cloud

Tobias Ortmaier

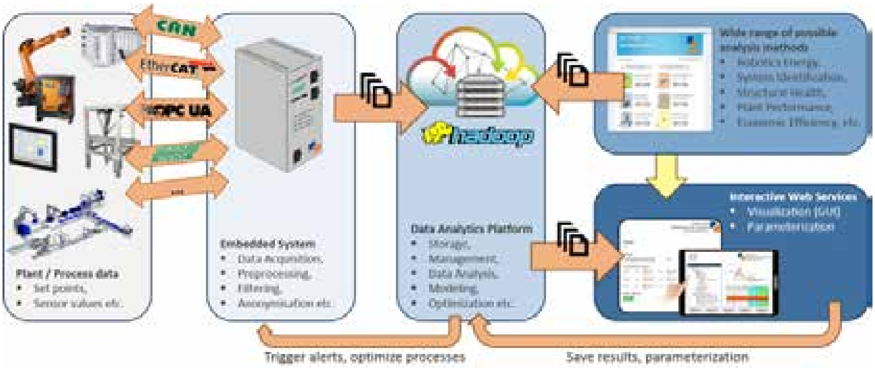
Industrie 4.0 is an enabler of the industrial megatrend smart factory. A prerequisite for the digitization of factories and production processes is the acquisition and interpretation of data. Mastering this challenge leads to both (a) an infrastructure linking the real-time automation level to a private (in other words not public) analytics platform and (b) easily deployable apps/services. The overall concept including an app-store and an interactive dashboard is sketched in Fig. 1.

The modular, scalable and hierarchical low-cost infrastructure not only allows for the seamless integration of new production lines, but also facilitates the retrofitting of existing ones. This is achieved through independence from manufacturers, based on the consistent implementation of standardized interfaces. First, a machine-orientated off-the-shelf preprocessing unit collects real-time data-streams (up to 1 kHz) either from the fieldbus (e.g. Ethercat, Profinet) or

the logic controller (e.g. via OPC UA or web services) and pre-analyses it in accordance with the installed services. The latter leads to a significant reduction in the amount of data being sent to the cloud. Thereafter, the results are anonymized, compressed and transferred to the analytics platform for further interpretation, e.g. based on machine-learning algorithms. This centralization and synchronization of various data-streams enables complex analyses, taking different production lines or even production sites into account.

In order to demonstrate the capability of the developed infrastructure, two example use cases were developed and implemented: energy optimization for a simple handling process involving several kinematics and fast error detection for a stacker crane. The respective results concluded the presentation.

Fig. 1: Concept of data acquisition and processing



Smart Products and Digital Industry

Dietmar Goehlich

The upcoming intelligent products communicate not only with us, the users, but also with other products and even with the production system when products on the assembly line tell shop-floor machinery how they are to be processed. Innovative digital business models offer completely new services. Smart Products in conjunction with Digital Industry 4.0 create a fully digital value chain, the 4th industrial revolution enabled by the Internet of Things.

Although this transformation process will largely be implemented by industry

itself, there is still a substantial need for research. The Technische Universität Berlin (TU Berlin), one of the largest universities of technology in Germany with a full spectrum of engineering supported by outstanding experts in mathematics and natural sciences as well as the humanities and social sciences, is addressing that challenge in numerous ways; only some of them can be discussed here.

Research and teaching at the Institute of Machine Tools and Factory Management revolve around the technological and management aspects of industrial factory operation. This includes the development of process technologies and production plants as well as their respective computer-based modelling. Two examples related to Industry 4.0 are presented in the following.

Virtual methods and simultaneous engineering are considered well-established tools in product development. Despite this, medium-sized plant manufacturers in Germany often still employ conventional development methods using a sequential development scheme. The joint research project "Virtual Start-up with Smart Hybrid Prototyping" (VIB-SHP) seeks to optimize the development process of production machines and entire plants using a virtual approach. Demands arising from Industry 4.0 are accounted for during all stages of development. For example, a methodology is developed to optimize the deployment of system control in production plants following their extensive evaluation at a virtual stage.

In current production facilities, multiple layers of control systems are separated by a strict hierarchy. Each control layer computes set points for its respective subordinate layers, based on measurements and static algorithms. The aim of this research project is to increase efficiency through the flexible deployment of control technology for cyber-physical systems in industrial production. The existing, monolithic control technology is broken up, reorganized into modules and extended by cloud computing methods, such as central data handling and service-orientated software architecture. This enables optimum utilization of expert knowledge available within the plant operator's or plant constructor's business. A cloud-based control system offers a suitable framework to supply aggregated computing power for cyber-physical systems in production technology.

These examples show how in a manufacturing environment, vertical networking, end-to-end engineering and horizontal integration across the entire value network of increasingly smart products will become feasible.

But the "Internet of Things and Services" will make its presence felt in other areas as well. This transformation is leading to the emergence of smart grids in the field of energy supply, sustainable and smart mobility systems and smart health. This far-reaching digitalization is addressed by many renowned research organizations. In which way should Berlin be able to compete successfully in this challenge?

In order to address these challenges, the TU Berlin recently initiated an Einstein Center Digital Future (ECDF), which will adopt an innovative structure going beyond already-known research structures. It implements – for first time on this large scale – a private / public partnership (PPP between 20+ industry corporations, governmental organizations, and other sponsors and all four Berlin universities, the Charité University Medical Center, and 10+ associated partners from the scientific community in Berlin.

The strategy of ECDF foresees focusing research on Digital Infrastructure, Methods, and Algorithms and three innovation areas:

- Digital Humanities and Society
- Digital Health
- Digital Industry and Services

In this presentation, some examples will be given of future research at ECDF in the areas of Digital Transformation and Smart Mobility, which will demonstrate the cutting-edge research of interdisciplinary methods, systems, and processes that merge knowledge from different disciplines thus exploiting the benefits of data-driven infrastructures in order to enable and develop future smart products.

PRESENTATIONS – Session 2
Advanced Implementation of Industry 4.0 and Academia-Industry Collaboration in Smart Manufacturing

Industrie 4.0 – Gateway for Industry Enabling the Digital Transformation
Reiner Anderl

Industrie 4.0 is an initiative of the German High Tech Strategy. Industrie 4.0 aims at improving added value in product engineering and production processes. The fundamental approach is to equip future products and future production resources with so-called cyber-physical systems. These cyber-physical systems are able to connect with each other and to communicate. Industrie 4.0 environments enable high flexibility, high adaptability and resilience. This contribution explained the fundamental principles of Industrie 4.0, how Industrie 4.0 has been transferred to industry so far and demonstrated use cases indicating its applications. Furthermore, an approach for the implementation of Industrie 4.0 in industrial enterprises was presented.

Industrie 4.0 at the Technical University of Munich
Gunter Reinhart

The Technical University of Munich (TUM) combines top-class facilities for cutting-edge research with unique learning opportunities for students. TUM was one of the first universities in Germany to be named a University of Excellence. Thirteen departments of the TUM provide an excellent environment for research and for the education of roughly 39,000 students. At TUM, there are 528 professors and 1,021 doctorates doing research. In 2015, 5,781 peer reviewed publications have been published.
At TUM and especially within the Department of Mechanical Engineering, the interest in the research area of Industrie 4.0 is strongly increasing. The Institute of Machine Tools and Industrial Management (iwb) is the largest institute at the Department of Mechanical Engineering and is represented by the Head of the Institute Professor Dr.-Ing. Gunther Reinhart.
Prof. Dr-Ing. Gunther Reinhart presented the TUM and the university's close linkages with Japanese universities, such as the University of Tokyo. In an overview of ongoing research activities at the TUM, in total eight research projects of five different institutes were presented. Each research project outlined practical examples focusing on the objectives, related challenges, implemented approaches and the results. The selected research projects addressed different Industrie

4.0 topics such as Big Data Analytics and Assistance Systems. Combined with different application areas (e.g. assembly line production and supply chain), the research projects provided a broad overview of ongoing activities at TUM.
The presentation was concluded with a short summary and an outlook on how Industrie 4.0 will influence the future of research in the area of production and at TUM in general.

Abstract: Toolbox for the Efficient Implementation of Industrie 4.0 Based on Use Cases

Juergen Fleischer

Implementation of Industrie 4.0 is a challenge for small and medium-sized enterprises (SME). For a successful implementation of Industrie 4.0, it is imperative to deduce a strategic roadmap with small steps based on use cases. The deduction of such use cases requires a high level of creativity and an awareness of the competences within the SME. Therefore, a toolbox and a workshop concept have been derived together with the Mechanical Engineering Industry Association (VDMA) to first asses the competences of the SME, to create new ideas based on existing competences and internet technologies. Within this presentation both the concept and the toolbox were discussed, and the approach for the creative generation of ideas for Industrie 4.0 within SMEs using the example of a smart ball screw drive was outlined.
The toolbox has a dual focus: the product view and the production view. Within each toolbox, six application levels show the main requirements and functionalities for Industrie 4.0 products and production. Each layer features five development stages describing the implementation of Industrie 4.0.
The "Products" section is divided into the six application levels "Integration of sensors and actuators", "Communication and connectivity", "Functionalities for data storage and information exchange", "Monitoring", "Product-related IT services" and "Business models around the product". Each of these application levels features five development stages. These stages range, for example, from "no integration of sensors" up to "the product is reacting autonomously based on the derived data".
As an example, the use of a ball screw drive (BSD) was discussed. Currently used ball screw drives are mechanical components which have no functionality for

communication, have no sensors and no functions for data exchange. The use of such BSDs within a machine tool has three main challenges:
First, the BSD has to be built into the machine tool. After the mechanical integration, the ball screw drive's technical key parameters such as diameter, pitch and pitch error have to be implemented within the machine tool control. Second, a BSD is subjected to wear which will finally end its usage. This wear is not constant, and failure sometimes occurs at very short notice. This creates downtime and results in high costs for maintenance and standstill. Third, each BSD is individual. Although manufactured with the greatest of efforts, high quality standards and a lot of experience, each BSD varies in friction torque during its lifetime and pitch error. For reduced maintenance and high quality, it is therefore imperative to know the individual behaviour of each ball screw and adapt the maintenance strategy as well as the control to the individual drive.
These use cases of the BSD were discussed with regard to the Industrie 4.0 toolbox, and the challenges and the approach for their usage were shown. Finally, in a joint workshop, the use of the toolbox in the Japanese and German context was discussed.

Published by:
German Research and Innovation Forum Tokyo (DWIH Tokyo)
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Tokyo, December 2016

The DWIH Tokyo is jointly organized by the German Rectors' Conference (HRK) and the German Chamber of Commerce and Industry in Japan. It is funded by the Federal Foreign Office in Germany and supported by the German Federal Ministry of Education and Research.

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Professor Dr.-Ing. Sami Haddadin is Director of the Institute of Automatic Control at the University of Hanover.

Professor Dr.-Ing. Yasuyuki Nishioka is President of the Industrial Value Chain Initiative (IVI) and professor at the Faculty of Engineering and Design at Hosei University.

Professor Dr.-Ing. Tobias Ortmaier is Head of the Institute of Mechatronic Systems at the University of Hanover.

Professor Dr.-Ing. Gunter Reinhart is Director of the Institute for Production at the Technical University of Munich.

The German Research and Innovation Forum Tokyo

The German Research and Innovation Forum Tokyo (DWIH Tokyo) acts as an umbrella for German scientific and research interests in Japan. It presents German research organisations and innovative companies in a concerted effort, thereby strengthening scientific and economic cooperation with Japanese partners. The German Research and Innovation Forum Tokyo has been set up jointly by the German Rectors' Conference (HRK) and the German Chamber of Commerce and Industry in Japan.

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All TU9 members enjoy an excellent reputation both in Germany and internationally. They were founded in the age of industrialization and have shaped the development of engineering sciences ever since. Their scientific potential, range of studies and number of students have grown continually over a period of almost 200 years. This common ground forms the basis of the university association TU9.

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