Industry 4.0 in a Nutshell – What is really new?

7th International Conference on Virtual Machining

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Michael F. Zaeh, Prof. Dr.-Ing, TU Munich, Germany
(Institute for Machine Tools and Industrial Management)
### Agenda

Industry 4.0 in a Nutshell – What is really new?

1. Definitions, Enablers, Benefits, Opinions
2. The Digital Shadow and Data Acquisition
3. Additive Manufacturing is Part of it
4. Artificial Intelligence – two Examples
5. Industry’s Position and Approach
6. Recommendations and Summary
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Definitions, Enablers, Benefits, Opinions

Industry 4.0

- **Industry 4.0** is an initiative of the Federal German Government in cooperation with Industry, which is striving to secure Germany’s top position by empowering it with respect to digital tools and methods.

- A major goal is the **Smart Factory**, which is characterized by changeability, resource efficiency, ergonomic design as well as integration of business partners in the processes.

- The term was introduced in 2011 during the Hanover Trade Show. In October 2012 the Federal German Government introduced recommendations concerning Industry 4.0.

To bring it to the point:

- **Use of networked systems** of all kinds within and between factories as well as towards customers and suppliers (Cyber-Physical Systems (CPS) and Cyber-Physical Production Systems (CPPS))

- The **connected mode** (*Internet of Things, Internet of Everything*) allows for the accumulation of data on a large scale and for the extraction of certain patterns (**Big Data**), also for new business models.
Cyber-Physical Systems (CPS) and Cyber-Physical Production Systems (CPPS) are main elements of Industry 4.0. (= Mechatronic systems, which communicate via a data infrastructure, for example the Internet) - Internet of Things (IoT).

CP(P)S dominate future production and logistics scenarios as
…intelligent products and
…intelligent production equipment.

CP(P)S in production connect themselves ad-hoc and thus allow for
…decentralized, highly reactive control systems,
…the increased use of decentralized intelligence,
…situation dependent control structures as well as
…an effective integration of people in production.

CPPS interact with intelligent CPS-products; CPS as a device in production
Added value in production because of Industry 4.0

- Increase of flexibility
- Smarter integration of the workforce
- Efficient use of resources
- Reduced time to market
- Improved competitiveness
- Powerful SCM
- Reduced peak loads
- Customer requirements better taken care of

*It is nothing but CIM reloaded.*

*Those who master it have a competitive edge.*
Definitions, Enablers, Benefits, Opinions

CIM = Computer Integrated Manufacturing (1980ies/90ies)
On the way to Industry 4.0

The digital twin/shadow from the supply chain all the way to the processes.

Cyber-Physical Systems allow the synchronization and merging of the real and the virtual world.
Definitions, Enablers, Benefits, Opinions

Where do we stand today?

The ideas are not new. However, today we have a better technological basis.

Expert opinions concerning the Status quo and concerning the achievability differ considerably, from …

Everything exists already!

… up to …

Completely utopian!
The idea of Industry 4.0 has already infiltrated our daily routine.

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<th>Past</th>
<th>Present</th>
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<tr>
<td>• Money transfer via a written check or money order</td>
<td>• Internet Banking</td>
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<td>• Travel agencies</td>
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<td>• Ticketing at a counter</td>
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<td>• Clarification of organizational and legal aspects</td>
<td><strong>• Clarification of organizational and legal aspects (returns, cancellations, ...)</strong></td>
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<td>• Web-security as a permanent task</td>
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“Industry 4.0“ has reached the private sector a long time ago.
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Simulation of the Thermal Behaviour / How to get to the Model Quickly

- Software tool for semi-automatic creation of a thermal model …
- transforms mechanical models into thermal models including …
- definition of the constraints (conduction, convection, radiation).
Motivation and goal

- Currently **time and cost intensive** integration of CPS in machine tools
- Idea of the USB-interface: **Plug & Produce**

Approach

- New industry specific interface for **energy and data transfer** into and from rotating systems
- Design such that **retrofit** is possible
- Software architecture for the integration of the CPS into a **machine tool control system**
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Additive Manufacturing is Part of it

The powder bed based Additive Manufacturing …

... is characterized by a completely integrated process chain.
Additive Manufacturing is Part of it

Additive Manufacturing of a Reamer (reaming tool holder)

Motivation:
- External reamers require high precision (e.g. for valve spool finishing)
- Lightweight design is good for dynamic behaviour
- Laser Beam Melting (LBM) of titanium and steel alloys

Approach:
- TiAl6V4 as standard alloy for lightweight applications
- 1.2709 (X3NiCoMoTi18-9-5) as standard steel alloy
- SLM 250HL machine, 400 W YLR-fibre laser

Results:
- Process was adopted by industrial partner Mapal (with further development)
- Approximately 54% mass reduction resulting in lower vibration amplitudes during the machining process

Source: Fraunhofer IWU/IGCV
Additive Manufacturing is Part of it

Additive Manufacturing of Gears

Motivation:
- Lightweight design and functional integration is also increasing in gear manufacturing using case hardening steels
  ➔ Laser beam melting of case hardening steels

Approach:
- Reference alloy: ASTM 5115 (16MnCr5)
- EOS M270 machine, beam source: 200 W Ytterbium fibre laser
- Process sequence: stress relief annealing, case hardening, hard finishing

Results and outlook:
- Average mass reduced by 25 %
- Conformal cooling for high temperature transmission
- Shorter lead times and process sequences
Additive Manufacturing is Part of it

Geometrical Features are for free, because …

… the manufacturing costs of a part are not determined by the features, but predominantly by the part volume.
Additive Manufacturing is Part of it

Topology Optimized Osteosynthesis Plates

design space B
additive manufacturing without post-processing (Electron Beam Melting EBM)

topology optimized implant A
subtractive manufacturing (milling)

design space C
additive manufacturing with post-processing (Electron Beam Melting EBM)

mandible

fibula segments
Additive Manufacturing is Part of it

Hybrid Approach Integrating Additive and Cutting Technologies

Laser Cladding  Laser Cladding  Milling

DMG Mori Lasertec 65 3D  (also on www.youtube.com)

Source: DMG Mori
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An *Evolutionary Algorithm* in Job Order Planning

Description of the Initial Situation: Assembly of Household Appliances (Dish Washers etc.)

- Manual planning of the job order sequences based on input (forecast) from sales and distribution
- 8 assembly lines with different capacities and capabilities; high set-up costs when changing from one batch/lot to another
- Manual optimization not possible due to high number of solutions, constraints and interdependencies
Artificial Intelligence – two Examples

An *Evolutionary Algorithm* in Job Order Planning

Description of the Initial Situation: Assembly of Household Appliances (Dish Washers etc.)

Manual job order planning for the next day on the basis of set-up codes (indicating similarities among the models and thus in set-up and line requirements)

![Diagram of assembly lines and set-up codes](image_url)
Artificial Intelligence – two Examples

An *Evolutionary Algorithm* in Job Order Planning

Description of the initial situation: assembly of household appliances (Dish Washers etc.)

- Manual planning on the basis of SAP planning charts
- Sequencing done iteratively based on set-up code and experience of the person in charge (2 hours per day)
Artificial Intelligence – two examples

An *Evolutionary Algorithm* in Job Order Planning

**Solution**

1. **Arbitrary initial population**
2. **Calculate fitness for all individuals**
3. **Select a number of the best individuals as parents for the next generation**
4. **Create next generation (partly randomized)**
5. **Check abort criterion**
6. **Final result**

The fitness function is:

\[
fit = \sum_{j=1}^{n} \sum_{i=1}^{a_j-1} r_{i;i+1} + G \sum_{j=1}^{n} (b_j - k_j) \times x_j
\]

- \( j \): Index of the assembly line (\( j = 1,2,\ldots,n \))
- \( i \): Index of the order on the assembly line \( j \) (\( i = 1,2,\ldots,a_j \))
- \( a_j \): Number of orders on line \( j \)
- \( r_{i;i+1} \): Costs for changing from order \( i \) to order \( i+1 \)
- \( b_j \): Capacity load of line \( j \)
- \( k_j \): Available capacity of line \( j \)

\( x_j \) = 1 \text{ for } b_j > k_j \text{, otherwise } 0

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Artificial Intelligence – two Examples

An Evolutionary Algorithm in Job Order Planning

Results

... achieved in an industrial project involving two PhD candidates and one student

- In use since 2005
- Planning time reduced from 2 hours to 10 minutes per day
- Increased quality of the planning result (= better fitness)
- Reduced costs for material and line use
- Increased productivity
Artificial Intelligence – two Examples

**Artificial Neural Networks and Evolutionary Algorithms** to Minimize Welding Distortions

- Laser Welding induces deformations of the workpiece, which are hard to predict and to control.
- Finite-Element-Simulation is possible, but very time-consuming.
- The accuracy of the workpiece depends on a multitude of parameters.

Welding job with many possible sequences

FE-model: mesh, constraints and clamping situation

Calibration of the heat source model

Source: Schober, Belitzki, iwbiwb
Artificial Intelligence – two Examples

Artificial Neural Networks and Evolutionary Algorithms (EA) to Minimize Welding Distortions

- **Evolutionary Algorithm:** beneficial for calibration of the Heat Source Models
- **Artificial Neural Network:** capable of handling the multiplicity of parameter settings
- **Evolutionary Algorithm:** determines the minimum distortion at the final joint closing the frame

![Diagram of Artificial Neural Network and Evolutionary Algorithm](image-url)
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Industry’s Position and Approach

Bosch Rexroth Group (AG) … is implementing pilot projects

- Bosch Rexroth (a manufacturer of drive and control technology) is implementing Industry 4.0 on the shop floor step by step … small but quick steps
- Gain experience in pilot projects (there are more than 100 such projects in the Bosch-group)
- Semi-automatic production line with more than 200 different hydraulic valves
- Via an RFID-tag the workpiece authenticates itself at the machines
- Bosch contributes to standards in different national and international committees
Industry’s Position and Approach

General Electric Company Corporation Definitely Sees High Significance …

- Industry 4.0 and the Internet of Things are of high significance for General Electric
- Data based services for the customer aiming at a more efficient use of General Electric products (jet engines, trains, power plants, wind energy plants)
- Predict-and-Prevent-Model instead of a repair oriented approach
- Just like Bosch, GE also contributes to standards in different national and international committees.
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Recommendations and Summary

Support for Industry

- Implementation of demonstrators / prototype applications
- Implementation of education and training centres
- Technology transfer
- Contributions to technical standards
- Less talking / more action
Recommendations and Summary

- **Industry 4.0** stands for the vision of a fully interconnected production system.

- **Objectives** are (among others):
  - Increased flexibility (lot size 1)
  - Increased productivity
  - Reduced time to market

- **Industry 4.0 is not a job killer, it is a job creator**, because it does improve the competitiveness of enterprises, which use it wisely.

- **Industry 4.0 is not a revolution**. Everyone still has the chance to come aboard.

- Everything has to be developed and earned. **There is very little that can be purchased off the shelf.**
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The Garching Campus of TU Munich

Some numbers: Founded in 1868, 14 departments, 500 professors, 10 000 staff, 40 000 students
Fields of Research at *iwb*

**Institute for Machine Tools and Industrial Management**

**Factory Planning**  
(Prof. Reinhart)  
Technology Management, Human Factors, Bionics

**Machines and Robots**  
(Prof. Reinhart, Prof. Zaeh)  
Structural Behaviour, New Applications

**Technologies**  
(Prof. Zaeh)  
Cutting, Joining,  
Additive Manufacturing
Our laboratory

2 prof., 61 researchers, 17 supporting staff, 6 management team, budget 10 MEuro p.a.
Michael Zaeh
Prof. Dr.-Ing.

Institute for Machine Tools and Industrial Management
Faculty of Mechanical Engineering
Technical University Munich
Boltzmannstraße 15
85748 Garching
Tel. +49.89.289.15502
Fax +49.89.289.15555
Michael.Zaeh@iwb.tum.de
www.iwb.tum.de