Digital Twin for Anomaly Detection and Runtime Tests in Industry 4.0

Prof. Dr.-Ing. Dr. h.c.

Michael Weyrich

Dec., 2020

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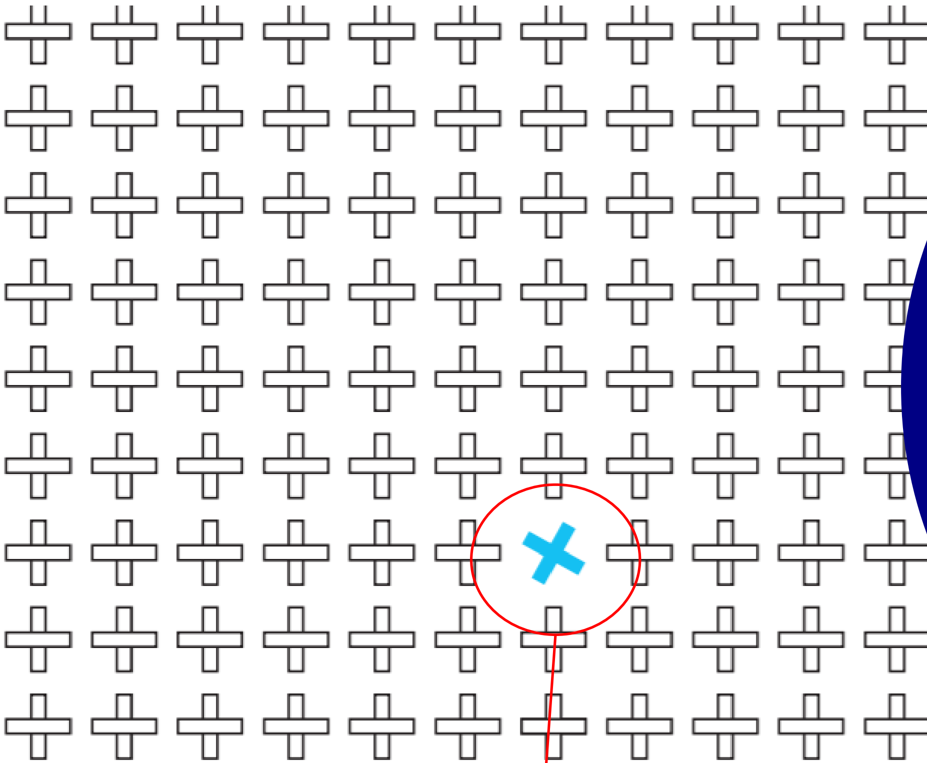

Anomaly detection is the identification of rare items, events or observations which raise suspicions.

Abstract

Digital Twin for Anomaly Detection and Runtime Tests in Industry 4.0

Prof. Dr.-Ing. Dr. h.c. Michael Weyrich, Dec., 2020

Digital Twins have been described as beneficial in many areas, such as virtual commissioning, fault prediction or reconfiguration planning. The presentation describes the use of the Digital Twin for anomaly detection and runtime tests. Digital Twins support artificial intelligence functionalities and can greatly expand those opening up new areas of application.

The presentation sketches applications of anomaly detection and runtime tests in design and operation, based on three scenarios from present research projects. The presentation concludes with a summary and a outlook towards cognitive sensor systems.

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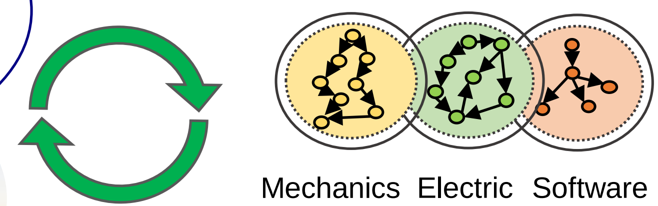
Digital Twin of Technical Systems

A cyber representation is created in unison with the physical system.

Physical Realization

Digital Twin



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Digital Twins are an established concept and are beneficial to many areas such as virtual commissioning, fault prediction or reconfiguration planning

Data Economy is a Key to Industry 4.0

Research shall strengthen the data economy in the value chains from the product, the supply chain to the production systems.

The central approach is the overarching use of data

- in distributed and modular systems
- across company boundaries throughout the value chain

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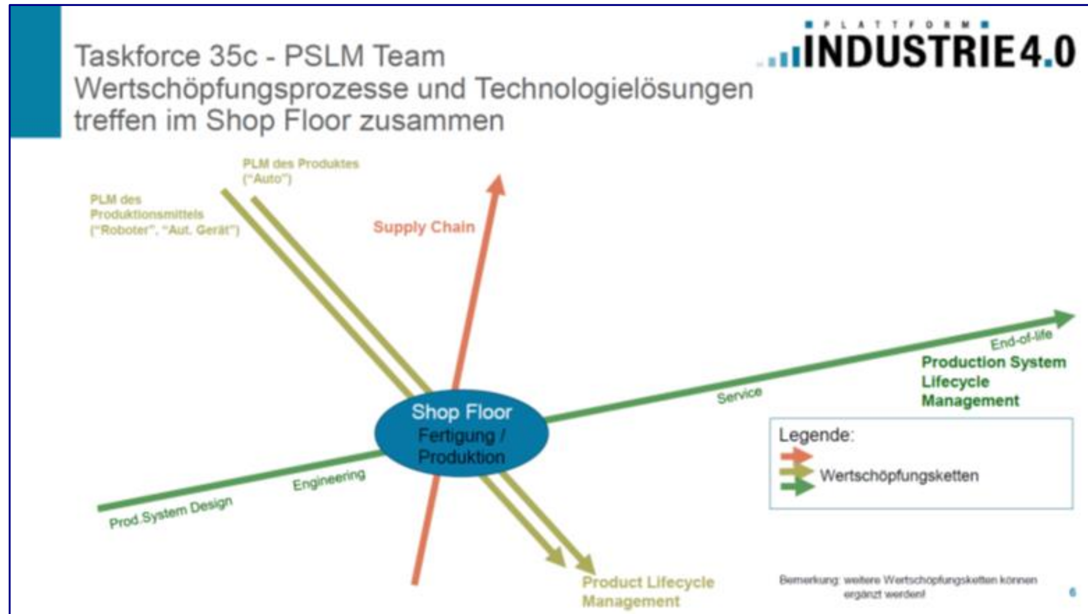

Original slide from the task force prepration team for the kopa35c initiative run by Plattform Industrie 4.0 for BMWi [1]

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Example 1: Intelligent clamping devices based on cognitive sensors

Development of sensor technology, electronics and software for data acquisition and analysis for condition monitoring of the component.

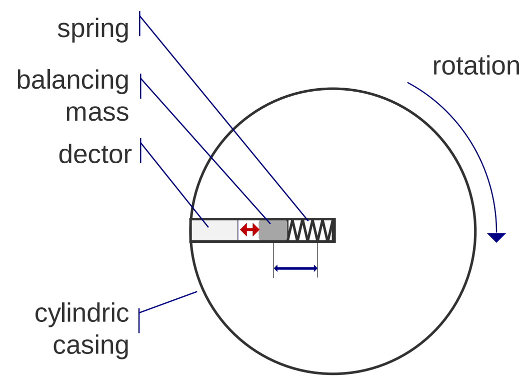
In the operation of chucks, imbalances occur, causing quality problems and production losses due to rejected parts

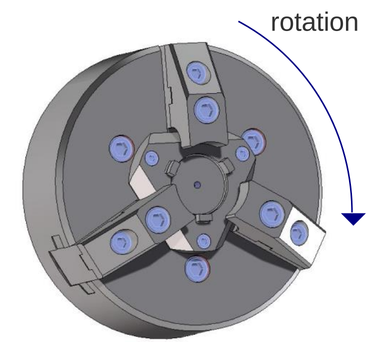
Required is an intelligent Monitoring of the clamping condition in operation.

- Resilient and with a long endurance
- Low energy
- Low cost

clamping devices for lathes

Picture: klopfer-tooling.de

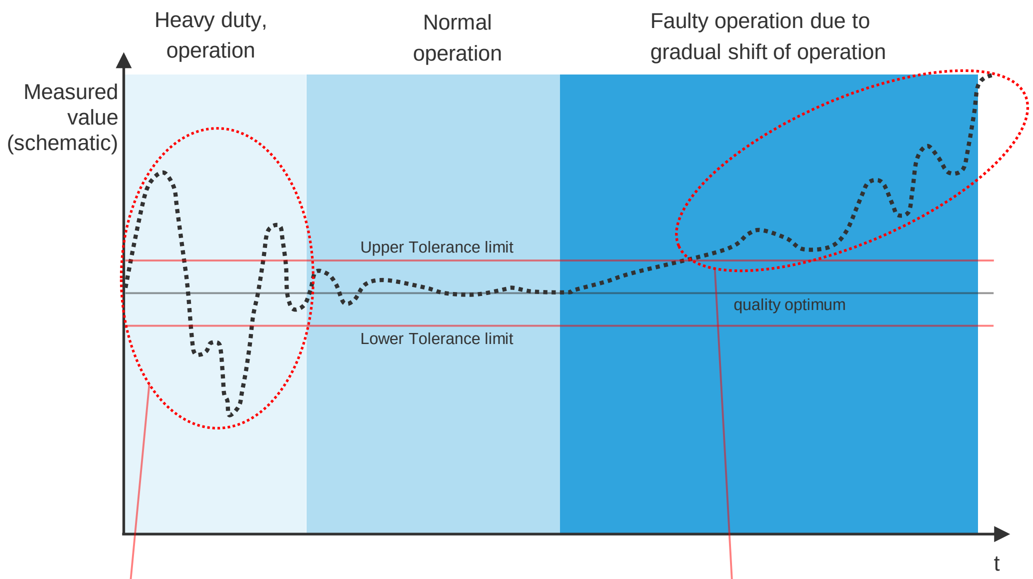




Example 1: Challenges for the intelligent Clamping

Challenges:

- Develop appropriate sensor which fulfils the requirements in the shopfloor
- Sensor hardware needs to be resilient to various operation modes and disturbances
- Intelligent processing software needs very well designed algorithms (But: there is limited data and even unknown use cases)

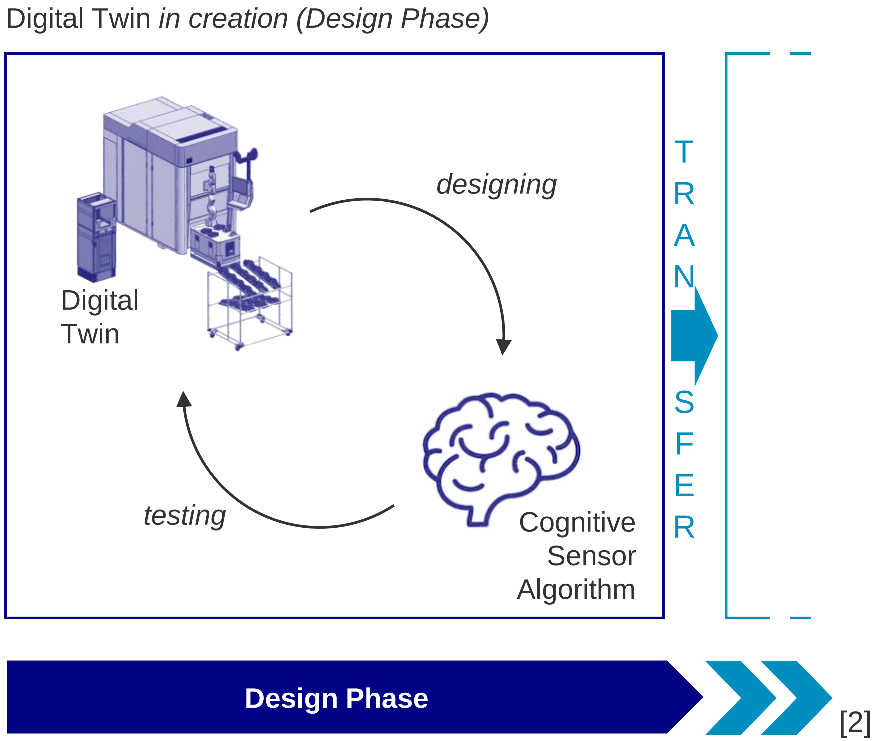


- Oscillation due to borderlining operation mode

- Gradual wear of clamming device

Example 1: Design of Cognitive Sensor function during Design

The Digital Twin is created based on experience and knowledge of the engineers. Typically very limited data and test cases are available.



Typical Issues:

- Unavailability of data restricts training with ML learning and test of algorithm
- No concepts available for transfer learning during operation at customers side

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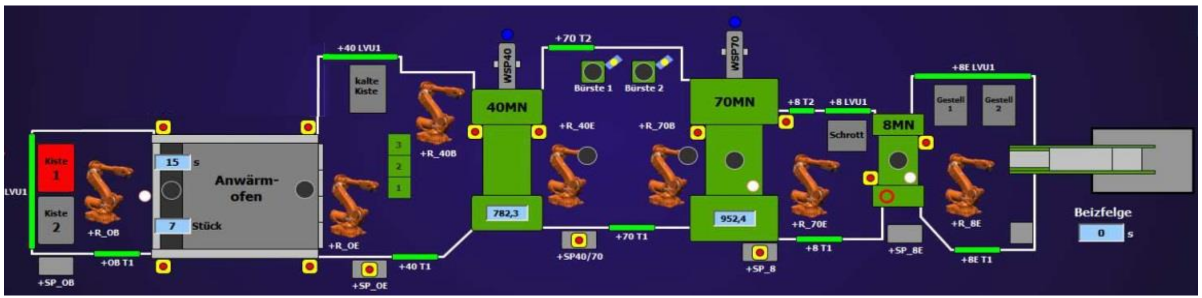
Example 2: Quality and Efficiency boost in Massive Forming

Optimize quality of the interconnected manufacturing process, machines and systems, people and products.

Quality check with nondestructive testing methods

Production line for Wheel Rims *(at Otto Fuchs KG)*

raw parts



wheel rims

As-is Situation:

abrupt and gradual anomalies in large scale production lead to fluctuating product quality

Desired:

Avoid fluctuating product quality and run operation with adaptive setting for compensation of abnormal process behavior ☞ Intended Result: Constant product quality

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Example 2: Quality and Efficiency boost in Massive Forming

The numerical modeling of the processes with a spatial and temporal distribution as well as material and thermal physics are very complex.

- No analytical models available for a numerical approximation of material properties and thermal physics
- FEM simulations capture the entire expert knowledge but are not applicable as prediction models

Machine Learning based on Simulation (LSTM-based modeling)

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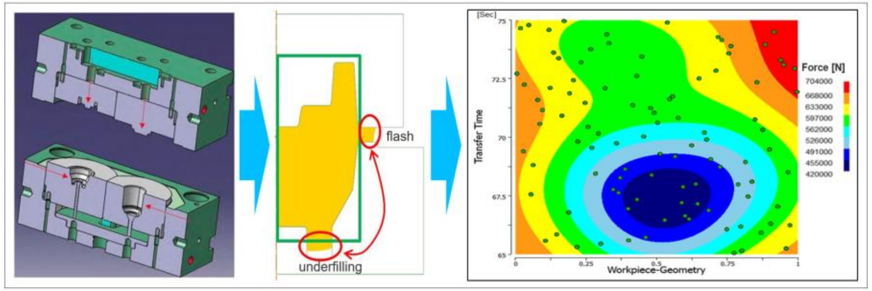
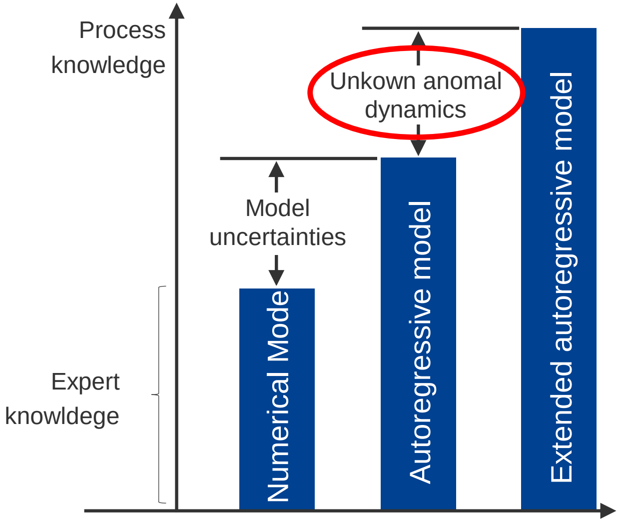
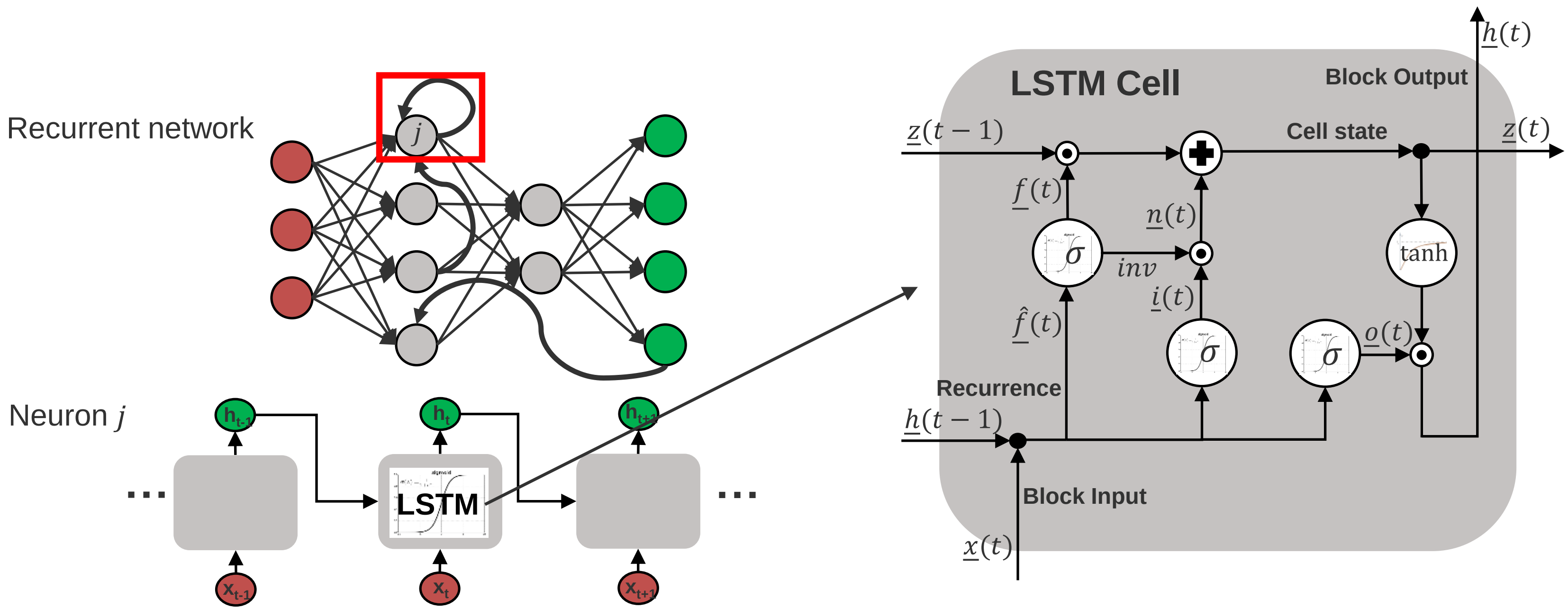




Example 2: Net and Cell Architecture

LSTM models short-term and long-term dependencies whereby stationary and non-stationary dynamics are modelled.



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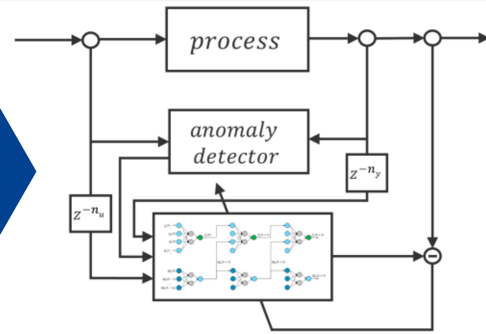
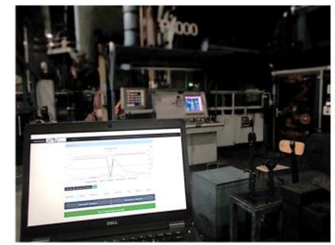
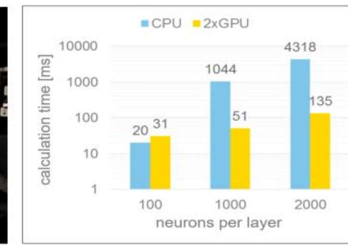
Empirical investigations (1): Anomaly detection

- Production line at Otto Fuchs KG for evaluation
- Investigation of pump system of hydraulic press
- Data: size of 2 TB, 86 parameters, 4 months







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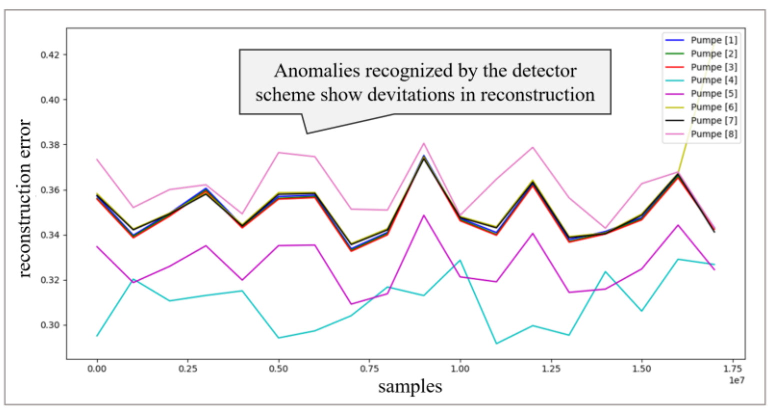
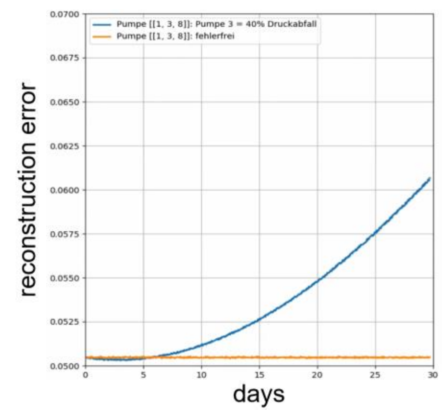
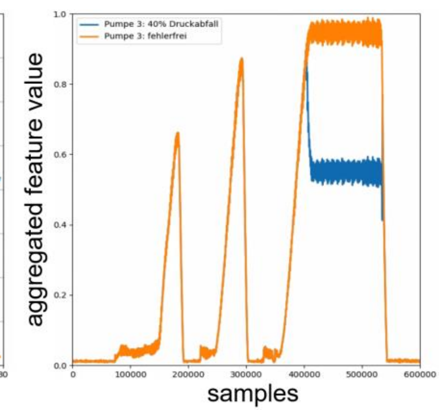
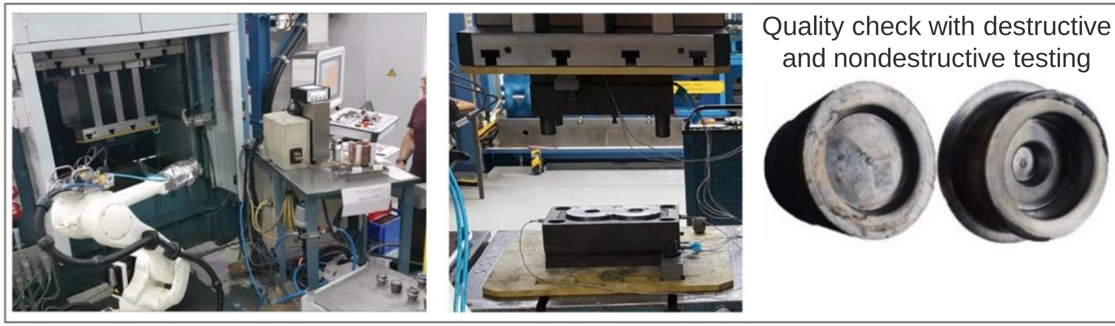


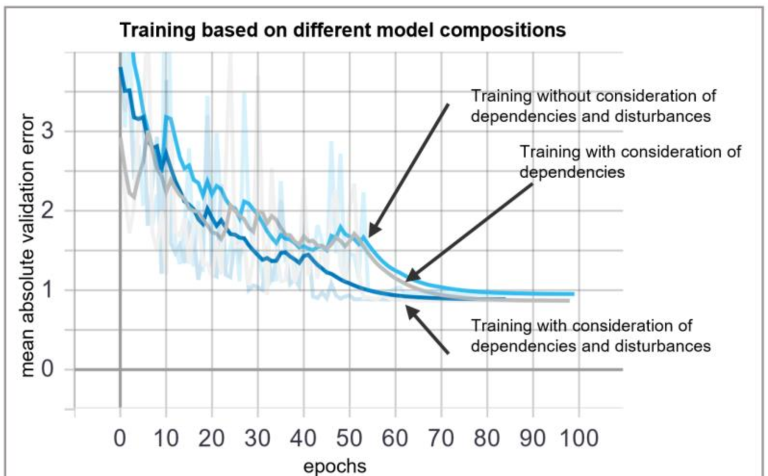


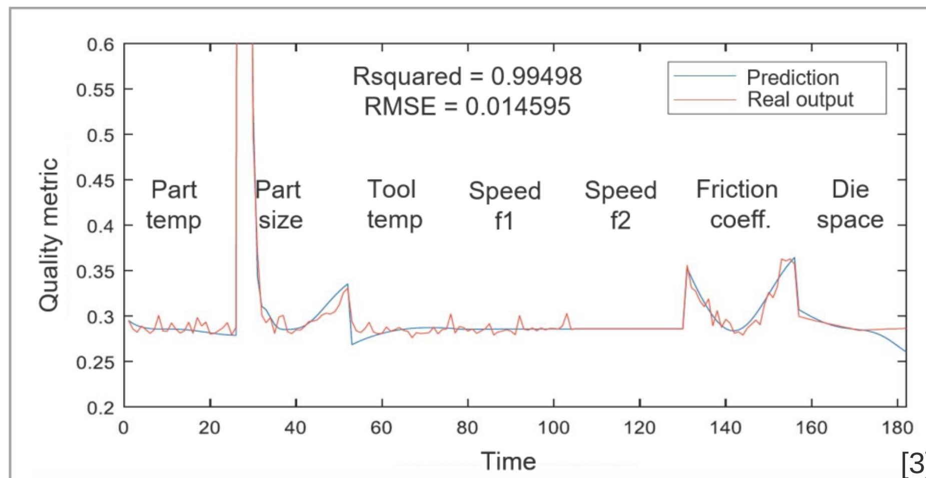


Empirical investigations (2): Process chain and training

- Production line at Univ. of Stuttgart (IFU) for evaluation
- Investigation of process chain with hydraulic press
- Pre-training with 4000 parts, further tests with 150 parts







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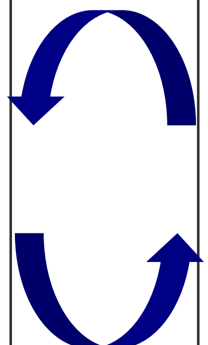
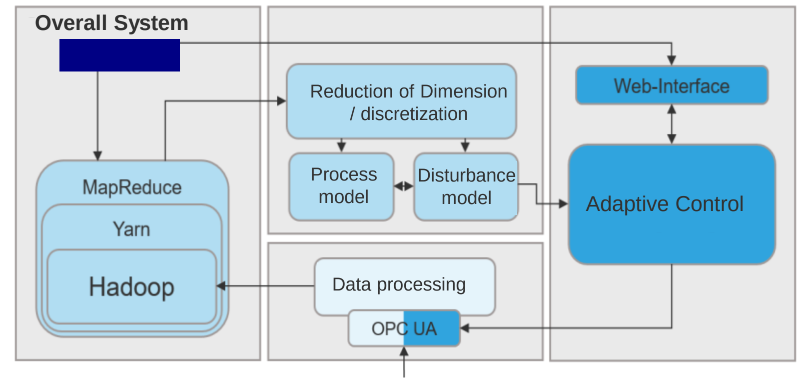
Realisation: Cloud-based cognitive anomaly detection system

Web-based assistant functions e.g. for adjustment of manipulated variables and Traceability.

Process chain at Univ. Stuttgart (IFU)



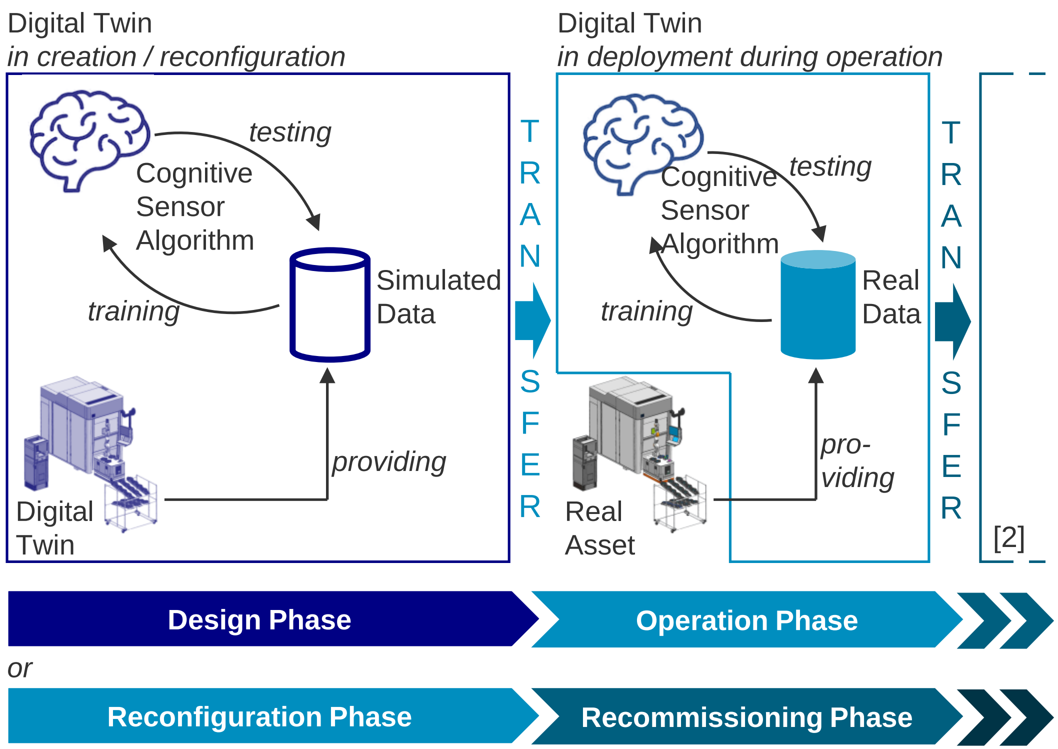


Manipulated variables adjustment

Traceability

Example 2: Design of Digital Twin based on Simulated and real Data

Pre-training can be carried out prior to operation to reduce the amount of data needed from the real asset, thereby speeding up the time for training.



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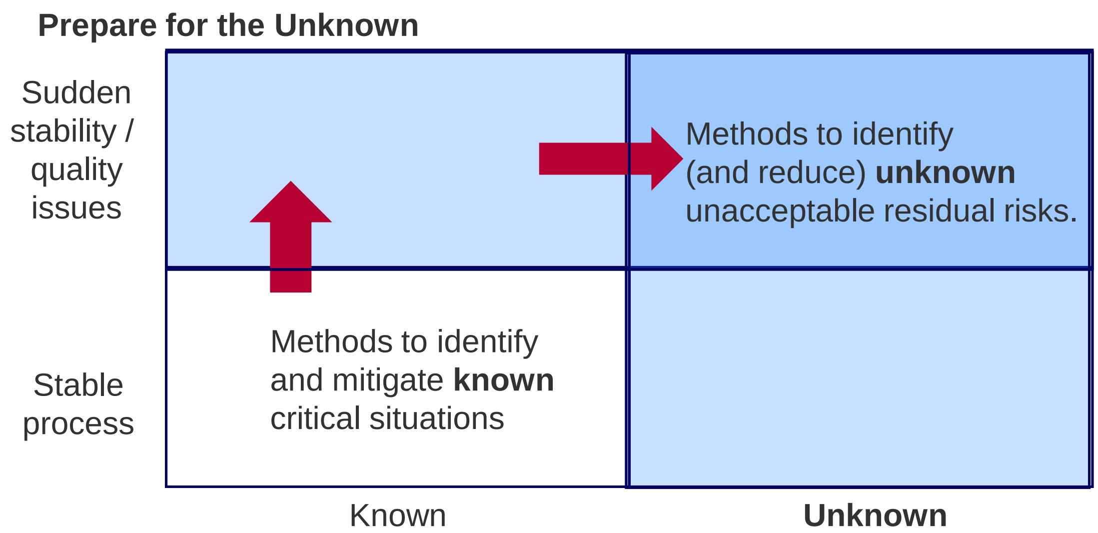
Example 3: Towards Autonomous Systems

Stability and quality of cognitive sensor becomes difficult to assess once complexity and decision making increases.



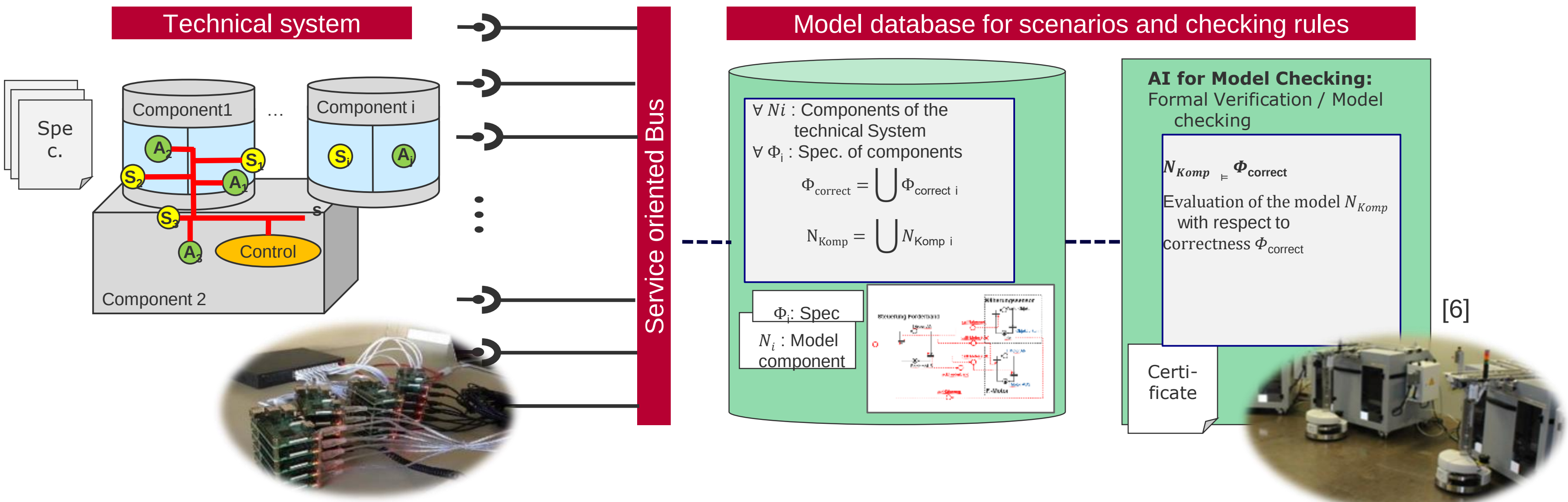
Model Plant at IAS at Universität Stuttgart

Example 3: Validation and Quality Control of Cognitive Sensors

Due to complex sensors including software which includes learning and advanced decision making, new ways of safeguarding are required.

Ensuring correct functioning through high test coverage of autonomous systems while guaranteeing operation

Modelling of dynamic systems for test management with need-based test initiation and automated test coordination



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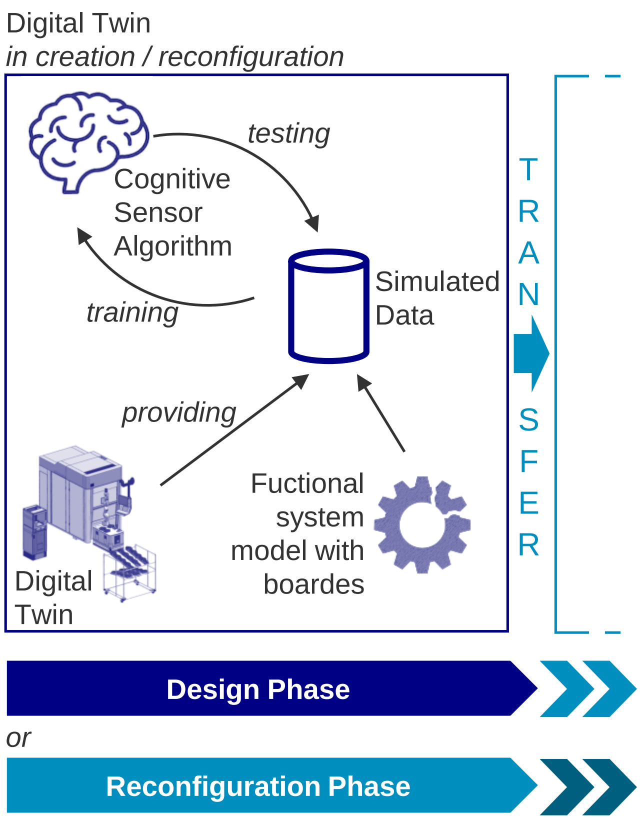
Example 3: Digital Twin models Functional boarders and Simulation

Autonomous system with cognitive sensors are simulated and checked with Formal Verification for violation with regard to functionality and quality.



Typical Issues:

- Autonomous systems with cognitive sensors takes action based on its own decision making and might violate functional or quality contingencies
- A functional system model alarms once defined boards are violated

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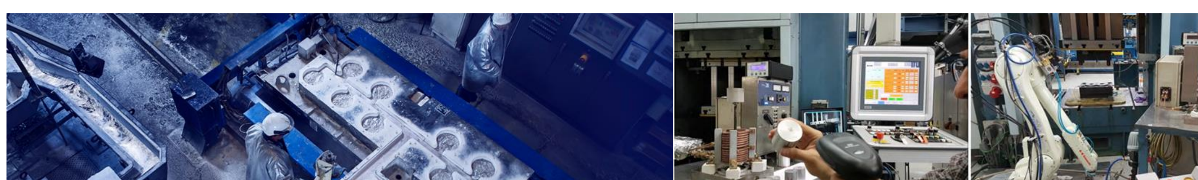
Conclusion and Outlook

Three different ways have been demonstrated on how Digital Twin can be utilized for Anomaly detection and Test.

- A deep knowledge of the technical process is required to setup applications
- A combination of IT / Electronics along with a software / algorithms competence needs to be available
- Considerable efforts are required to operate and maintain Digital Twin applications which are rather monolithic

- **Cognitive sensor** and means of integrating those into control solutions are required to decompose monolithic system solutions of today.
- To capitalize economically on anomaly detection and runtime testing **distributed components and modular solutions** are essential for success.



References

[1] BMWi: Zukunftsinvestitionen für Fahrzeughersteller und Zulieferindustrie, abgerufen 13.12.2020,https://www.bmwi.de/Redaktion/DE/Textsammlungen/Industrie/zukunftsinvestitionen-fahrzeughersteller-zulieferindustrie.html.

[2] B. Maschler, D. Braun, N. Jazdi, M. Weyrich: A Transfer Learning as an Enabler of the Intelligent Digital Twin, 31st CIRP Design Conference, 2021 (submitted).

[3] B. Lindemann, N. Jazdi, and M. Weyrich, “Anomaly detection and prediction in discrete manufacturing based on cooperative LSTM networks,” in IEEE 16th International Conference on Automation Science and Engineering (CASE), 20-21 Aug. 2020, Hong Kong, 2020.

[4] M. Müller, B. Ashtari Talkheshtani, N. Jazdi, R. Rosen, J. C. Wehrstedt, and M. Weyrich, “Informationsmodelle mit intelligenter Auswertung für den Digitalen Zwilling,” in Automation 2020, VDI-Bericht Nr. 2375, VDI Wissensforum GmbH, Düsseldorf, 2020, pp. 659–673.

[5] A. Zeller, N. Jazdi, and M. Weyrich, “Functional Verification of Distributed Automation Systems,” in The International Journal of Advanced Manufacturing Technology, Springer, published online: 03.07.2019, 2019.

[6] C. Ebert and M. Weyrich, “Validation of Autonomous Systems,” IEEE SOFTWARE, vol. 36, no. 9/10, pp. 15-23, 2019, 2019.