Smart Components

Research Group TEC | Manufacturing Technology

White Paper

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Table of contents

1. The Cluster Smart Components within the TEC research group

1.1. What are Smart Components?

In the digital transformation, smart parts and components have a central position. Smart components are parts or components that are equipped with sensory technology. The sensor data collected is processed and evaluated within the component. Physical, mathematical, or data-based models based on existing data sets are used for this purpose and can make autonomous decisions. Communication interfaces allow the information to be forwarded to other systems. An example of this is the wear evaluations of protective covers based on real-life stress and the associated decision on when to perform maintenance. By adding actuator functionality to the sensory functionality, the component information and decisions can be integrated into control loops. For example, vibration reduction can be realized through actuator-based countermeasures.

1.2. Research group TEC

Since the beginning of 2021, we have jointly formed the research group TEC | Manufacturing Technology within the Institute for Production Management, Technology and Machine Tools (PTW) at Darmstadt University of Technology. Our vision is to conduct trend-setting research for data-driven, adaptable manufacturing technologies in resource-efficient, responsive production. Enthusiasm for our research, a high level of commitment and initiative, as well as openness and curiosity in breaking new ground are essential characteristics of our TEC team.

The TEC research group has grown together from the three former research groups *Additive Manufacturing*, *Machine Tools and Industrial Robots*, and *Machining Technology*. Thus, we are able to cover a broad field of manufacturing technology. Shortly after the changeover, the closer cooperation in the TEC research group became apparent through simpler communication, as well as more agile project application and processing. In order to address specific topics, the research clusters *Smart Components*, *Advanced Modeling*, *Connectivity & Communication* and *Monitoring & Control* were established in the TEC research group. However, these clusters do not represent strictly delimited groups, but are rather to be understood as open spaces for exchange among the colleagues. This enables a differentiated view of the topics from different directions and ensures a targeted exchange of experience and knowledge.

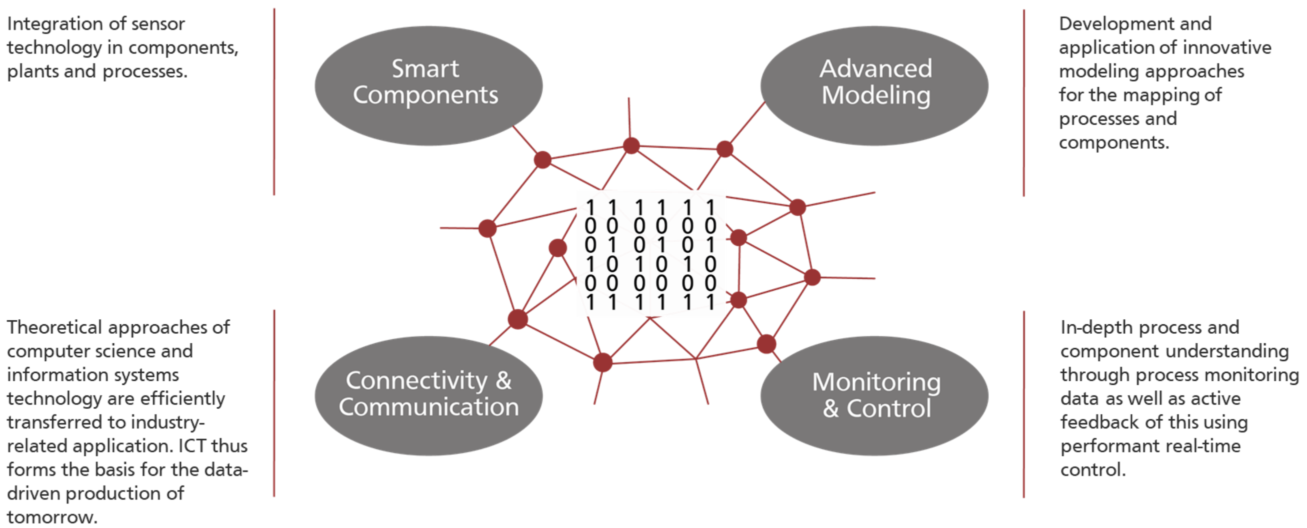

Figure 1: Expertise of the clusters within the TEC research group

With the TEC-Lab, PTW has a technical center with a climate-stable measurement and sample preparation room as well as modern machinery. It provides the perfect environment to quickly develop and test new approaches for data-driven manufacturing using agile methods in a solution-oriented manner. With various demonstrators for data-driven manufacturing technologies and networked production solutions, the fun and enthusiasm for data-driven production is also awakened among young scientists.

Figure 2: TEC-Lab at PTW

2. Smart Components in future machining

2.1. Vision

The application range of electronic systems such as embedded systems and sensors such as Micro-Electro-Mechanical Systems (MEMS) is constantly expanding due to progressive miniaturization, cost reduction and their robustness. The fields of application also include the development of smart components for use in industrial production, which, in addition to monitoring the condition of machines and systems, can also serve quality assurance with advancing technological development.

At its core, a smart component consists of linking data sources with programmed knowledge. The data sources are, for example, external sensors or sensors already integrated in the machine, which record relevant process variables and make them available. The so-called programmed knowledge can be stored in the form of algorithmizable models, whereby these, in contrast to Machine Learning (ML) algorithms, are not capable of further learning. A simple example of programmed knowledge is the verification of a threshold violation with subsequent decision making.

In the context of the TEC research group, the "Smart Components" cluster can be seen as an enabler for the "Monitoring and Control" cluster, since the process monitoring data can be provided by smart components, among other things.

2.2. Smart Components in machining application

In the context of digitization of production, networking and interoperability of machines and components are essential components. The challenges involved in integrating smart components into digitized production environments are not only of a digital nature, but also include system development with regard to metrological issues and system integration, which are explained in more detail below.

2.2.1. System development of Smart Components

The challenges in system development of smart components can be divided into metrological and system integration issues. The metrological issues are mainly the definition of suitable physical quantities to be measured and the associated measurement principles and sensor concepts. The challenges of system integration include concepts for energy supply and for minimizing the influence on the original system properties. The goal is to integrate the smart component systems into an existing system without significantly changing the static and dynamic compliance as well as disturbance contours (geometry). In addition, a robust communication interface is required, which is particularly relevant for rotating smart components in the field of high-speed machining.

If the smart components are multi-sensor systems with non-uniform data acquisition, challenges arise with respect to data synchronization, which leads to mandatory software time synchronization of the data streams. Depending on the use case of the smart components, real-time capable requirements must be met by the system to enable time-critical decision-making of the smart component.

2.2.2. Manufacturing integration

A function describes, in a solution-neutral way, the intended relationship between the input and output of the system with the aim of fulfilling a task. The component can fulfill more than one function and consist of one or more components. Function integration is understood to mean the combination of different functions in one component, where, for example, the number of components or the assembly effort is reduced by bringing them together. In most cases, a functionally integrated component is characterized by a compact design and use for lightweight applications. In addition to the categories of function integration by design (e.g. near-contour temperature control by means of novel channel structures) and function integration by process (e.g. generation of graded component properties by means of adapted process strategies), the integration of components is a cornerstone of function integration.

In current research, the manufacturing integration of sensor technology is a focal point in the field of component integration. The targeted integration of sensors enables the best possible data acquisition. These form the starting point for the data-driven production of the future. Furthermore, extended possibilities for noise and vibration reduction, shape and position control as well as damage detection arise.

The integration of components can be realized by means of different manufacturing technologies. At PTW, new integration methods are being researched in addition to component integration using conventional processes. In the technology field of additive manufacturing, approaches for the integration of actuators and sensors using powder bed-based laser beam melting are being advanced. Furthermore, sensors are integrated into components made of non-metallic construction materials such as ultra-high-strength concrete (UHPC) using innovative integration methods.

3. Projects and offers to the industry

3.1.1. SensoSchu

In the SensoSchu project, a flexible protective cover was extended to become a smart component. A methodology for selecting appropriate physical quantities to be measured for condition monitoring applications was developed and applied. Suitable sensors were identified for the measured quantities selected this way and integrated into the cover with low interference contours.

Since distributed sensors and a highly variant machine tool component are involved, an easily adaptable system architecture for distributed sensor systems was designed and prototyped (see Figure 3). The prototypes were operated on a test bench, thus recording data for analysis over a period of months. Suitable pre-processing and analysis using machine learning, among other things, made it possible to demonstrate a wear condition diagnosis of the protective cover using the integrated sensors.

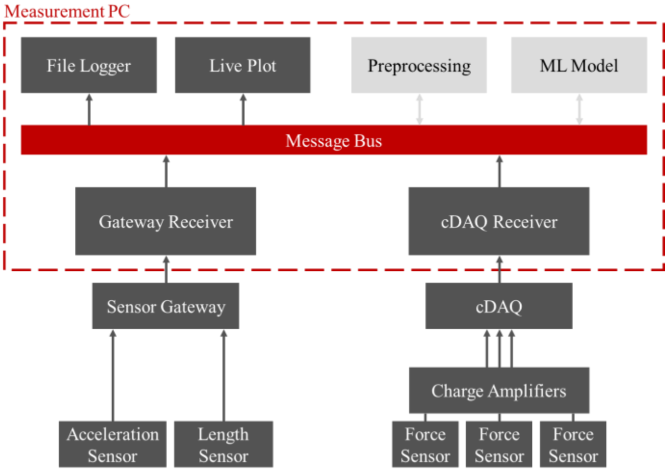

Figure 3: Exemplary system architecture of a smart component[1]

3.1.2. AddKraft

Structural Health Monitoring enables the detection of damage and improves maintenance service. The evaluation of the structural health requires sensor integration of mostly mechanical sensors (e.g. force, torque). Due to complex geometries of the structures, a simplified integration of conventional sensors is not possible or only with considerable effort. The use of metal-based, laserbased powder-bed-fusion (LPBF) of metals as an additive manufacturing process is a promising approach for the production of structurally integrated sensors that can be adapted to given structures.

One promising method is the integration of strain gauge sensor elements into an LPBF fabricated deformation body. For this purpose, strain gauges in full bridge configuration are applied to a conventionally manufactured stainless steel plate, which serves as measuring element carrier, and integrated into the deformation body by interrupting the additive manufacturing process.

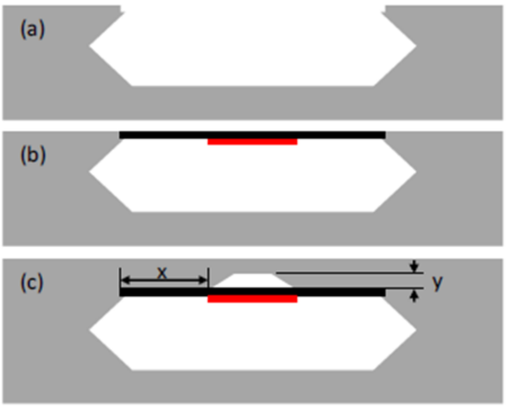

Figure 4: Integration principle of strain gauges in LPBF-manufactured components (a) Structure of deformation body by means of LPBF (b) Integration of measuring element support with applied strain gage (c) Complete encapsulation by means of LPBF

[1] F. Hoffmann, B. Brockhaus, J. Metternich, and M. Weigold, "Predictive Maintenance für Schutzabdeckungen", wt, 7-8, pp. 496–500, 2020

The novel method for manufacturing structurally integrated force sensors is advantageous in terms of complex geometry variants, individualization of the sensor and increased reliability due to better protection against environmental influences. In addition, great potentials open up in terms of miniaturization due to the functional integration of encapsulation and deformation body. These properties are particularly advantageous in areas such as structural and plant monitoring as well as in medical technology.

3.1.3. CRC805

The Collaborative Research Center 805 (CRC805) has dealt with the control of uncertainty in load-carrying systems in mechanical engineering. The research covered the control of uncertainty during the product development, the production and the use phase of technical systems. With focus on production engineering, the PTW Institute investigated uncertainty in tapping in the third funding period of CRC805. To detect process uncertainties in tapping process, a sensor-integrated floating tapping chuck was developed, Fig. 3, which is equipped with two new sensor concepts that allow detection of close-to-tool vibrations of the tapping tool as well as the axial length compensation.[2,3]

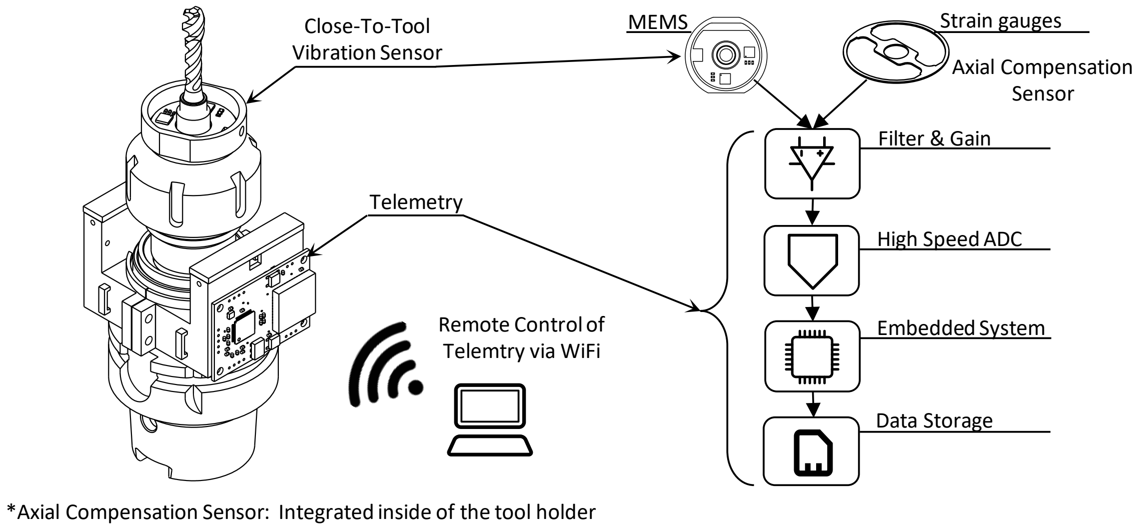

Figure 5: Smart tapping chuck for detection of process uncertainties

Data acquisition is performed by a high-resolution and high-frequency analog-to-digital converter in combination with a real-time capable embedded system, which form the telemetry unit. The control as well as the parameterization of the telemetry unit is done remotely via the standardized wireless interface WiFi. The measurement data which is sampled at up to 52 kHz is stored directly on the telemetry unit, thus enabling reliable post analysis of the measurement data to extract features for process uncertainty detection. The embedded system architecture is equipped with two processor cores and enables simultaneously the sampling as well as the analysis of the measurement data to detect uncertainty during tapping using predefined features.

[2] T. Öztürk, M. Weigold, „Sensorvorrichtung zum Erfassen werkzeugnaher Schwingungen beim Bearbeiten eines Werkstücks mit einem Werkzeug“, Patent angemeldet, amtliches Aktenzeichen / Application Number: DE 10 2021 100 465.9

[3] T. Öztürk, M. Weigold, „Sensorelement und Sensorvorrichtung zum Erfassen eines axialen Längenausgleichs in einem Längenausgleichsfutter beim Bearbeiten eines Werkstücks mit einem Werkzeug“, Patent angemeldet, amtliches Aktenzeichen / Application Number: DE 10 2021 100 466.7

4. Dissemination of knowledge

In addition to courses for students and industry partners, we implement the knowledge gained in demonstrators that serve to reinforce knowledge and provide training and further education. In the Smart Components cluster, there are several demonstrators that are intended to address the target group of industry on the one hand and students of mechanical engineering, computer science and mechatronics on the other. The demonstrators are intended to demonstrate the possibilities of smart components and to be experienced in minimal examples in the TEC-Lab. On the other hand, in interaction with processes on the machines in the TEC-Lab, they are intended to show the direct benefits in manufacturing for process description and, in connection with the research cluster Advanced Modeling, the potentials of data-driven models for process description. The basis for the demonstrators and their continuous further development are the considered use cases of the research projects.

5. List of Publications

- H. Stoffregen, "Funktionsintegration mittels selektiven Laserschmelzens am Beispiel strukturintegrierter piezoelektrischer Aktoren," in Rapid.Tech 2015 - Trade Fair and User's Conference for Rapid Technology, 10.-11.6.2015, Erfurt, 2015. [Online]. Available: http://tubiblio.ulb.tu-darmstadt.de/74300/
- T. Grosch, J. Schloen, M. Weigold, and E. Abele, "SmartTool++," Zeitschrift für wirtschaftlichen Fabrikbetrieb, vol. 114, no. 4, pp. 219–222, 2019, doi: 10.3139/104.112073.
- F. Hoffmann, B. Brockhaus, J. Metternich, and M. Weigold, "Predictive Maintenance für Schutzabdeckungen", wt, 7-8, pp. 496–500, 2020. [Online]. Available: http://tubiblio.ulb.tu-darmstadt.de/122403/
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- R. Chadda et al., "Disruptive Force Sensor Based on Laser-based Powder-Bed-Fusion," in 2020 IEEE SENSORS, Rotterdam, Netherlands, Oct. 2020 - Oct. 2020, pp. 1–4, doi: 10.1109/SENSORS47125.2020.9278934
- Bretz, E. Abele, and M. Weigold, "Measuring the bore straightness during reaming with sensoric tools," Prod. Eng. Res. Devel., vol. 14, no. 4, pp. 535–544, 2020, doi: 10.1007/s11740-020-00977-6.
- A. Bretz, F. Geßner, T. Öztürk, C. Rinn, and E. Abele, "Adjustment of Axis Offset Errors during Reaming," Applied Mechanics and Materials, Trans Tech Publications, Switzerland, pp. 267–275, 2018. [Online]. Available: http://tubiblio.ulb.tu-darmstadt.de/109973/
- B. Brockhaus, F. Hoffmann, J. Metternich, and M. Weigold, "Predictive Maintenance for Flexible Protective Covers in Machine Tools," in Lecture Notes in Production Engineering, Production at the Leading Edge of Technology, B.-A. Behrens, A. Brosius, W.-G. Drossel, W. Hintze, S. Ihlenfeldt, and P. Nyhuis, Eds., Cham: Springer International Publishing, 2022, pp. 177–185. doi: 10.1007/978-3-030-78424-9_20
- Öztürk, T., Sarıkaya, E. & Weigold, M. Sensor-integrated tap holder for process uncertainty detection based on tool vibration and axial length compensation sensors. Int J Adv Manuf Technol (2021). https://doi.org/10.1007/s00170-021-07825-6

Patents:

- T. Öztürk, M. Weigold, „Sensorvorrichtung zum Erfassen werkzeugnaher Schwingungen beim Bearbeiten eines Werkstücks mit einem Werkzeug“, patent pending, application number: DE 10 2021 100 465.9
- T. Öztürk, M. Weigold, „Sensorelement und Sensorvorrichtung zum Erfassen eines axialen Längenausgleichs in einem Längenausgleichsfutter beim Bearbeiten eines Werkstücks mit einem Werkzeug“, patent pending, application number: DE 10 2021 100 466.7

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