Workshop MUSP - Sensors and data fusion in mechanical processes Piacenza, April 10, 2013

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Fraunhofer Institute for Machine Tools and Forming Technology IWU Chemnitz

Department of Automation

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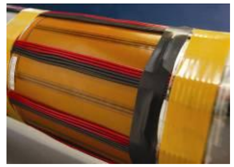
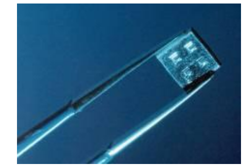
1. Fraunhofer IWU in profile
2. Example of a multisensory process control system
3. Experiments
4. Methods of data analysis
5. Results

The Fraunhofer IWU in Profile









Fields of expertise

- Machine Tools
- Mechatronics
- Lightweight Construction
- Forming Technologies
- Cutting Technologies
- Joining and Assembling
- Production Management

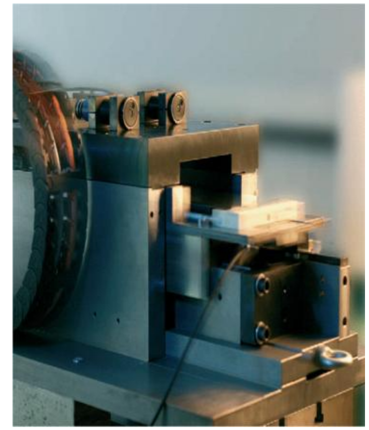
in close cooperation with

- Chemnitz University of Technology
- Fraunhofer-Gesellschaft
- Machine tool industry
- German and international automobile industry
- Ancillary industry (forming, cutting, tool and die making)

Archivierungsangaben

Department of Automation - structure





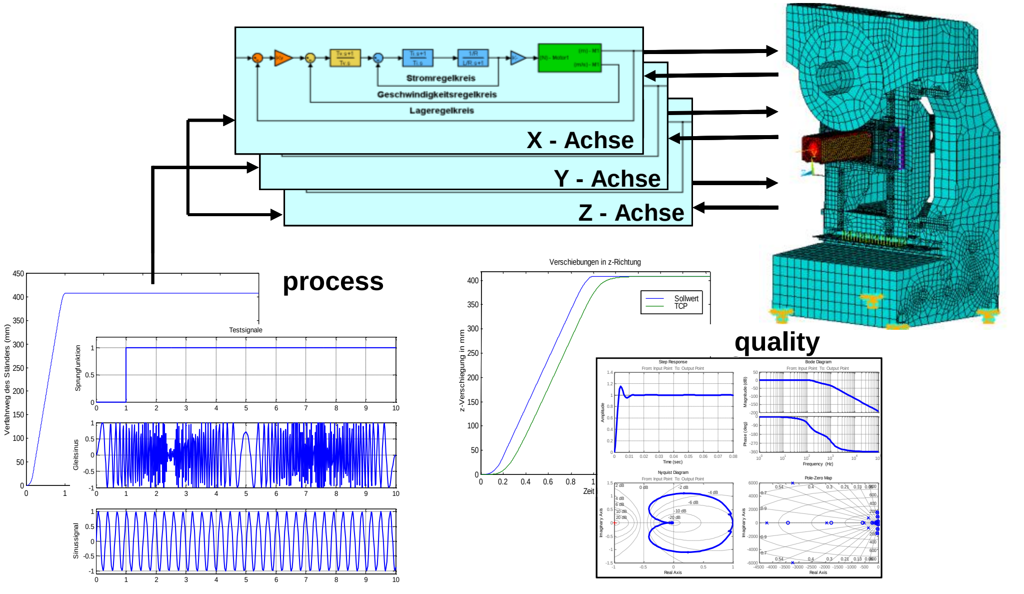
- Controls and Drives
- Information and Communication Technologies
- Machine and Process Analysis

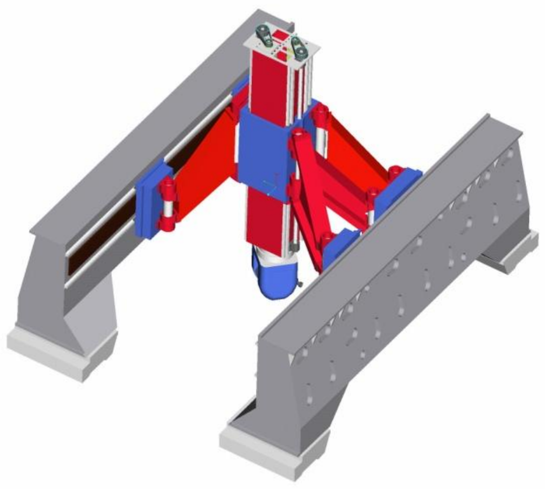
Department of Automation – core competencies

Controls and Drives

- design, draft and dimensioning of
  - electromechanical drive systems (i.e. direct drives and gear solutions)
- CNC-control solutions, NC-kernel-replacement or functional extension
  - transformation (parallel kinematics), compensation strategies, control structures (multi-axes-solutions)
- Simulation and property evaluation
  - drive / control – mechanical structure – process

adapted operation panel





machine tool with scissor kinematic

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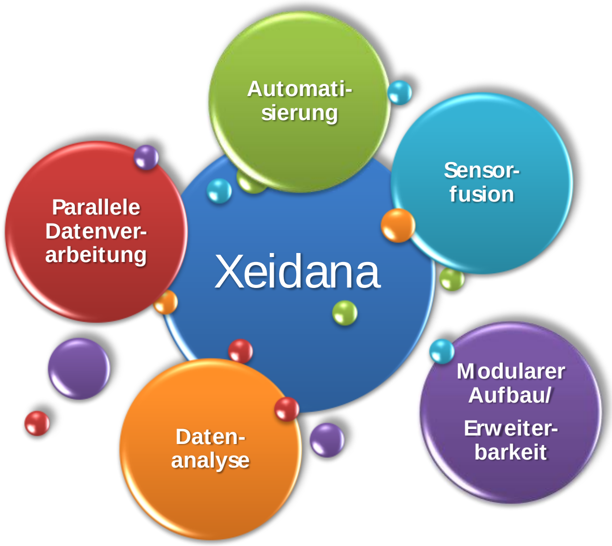
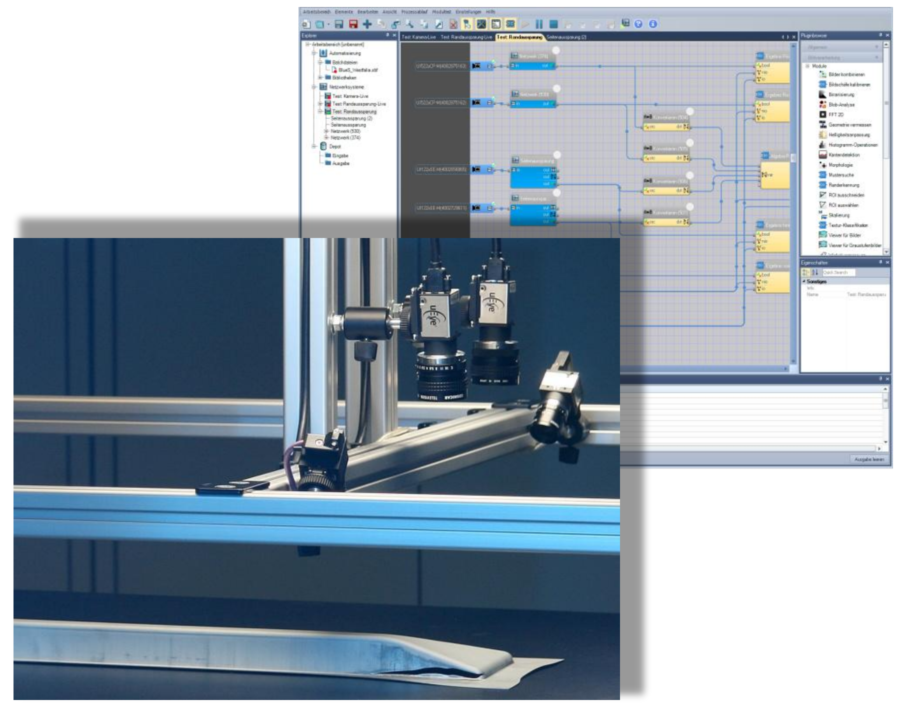
Department of Automation – core competencies

Process- and Quality Inspection

- multisensory data analysis
- imaging methods
- Xeidana® (extensible environment for industrial data analysis)





IWP WERKZEUGMASCHINEN UND PRODUKTIONSPROZESSE

Fraunhofer IWU

Quality Control of Resistance Spot Welding of High Strength Steels

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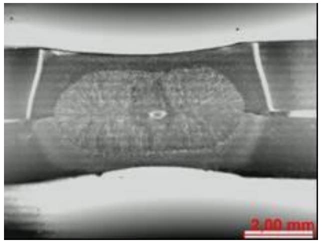
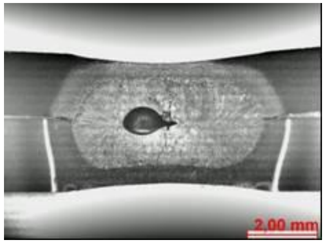
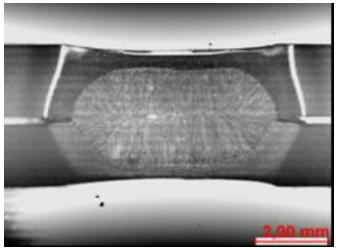






Motivation

- Increasing demands for body in white manufacturing require new solutions for material and manufacturing → increasing use of high strength metal sheets
- Resistance spot welding is a joining process established for body in white manufacturing and reached a high level of reliability using controlled welding systems
- In order to achieve a zero defect manufacturing → additional requirement to demonstrate the achieved quality of resistance spot welding in-line

Initial situation

- Previously testing methods primarily focused on monitoring and control of welding current and welding time
- Strength of the individual spot welds usually tested manually by
  - Nondestructive ultrasonic methods
  - Randomly via destructive methods like chisel testing

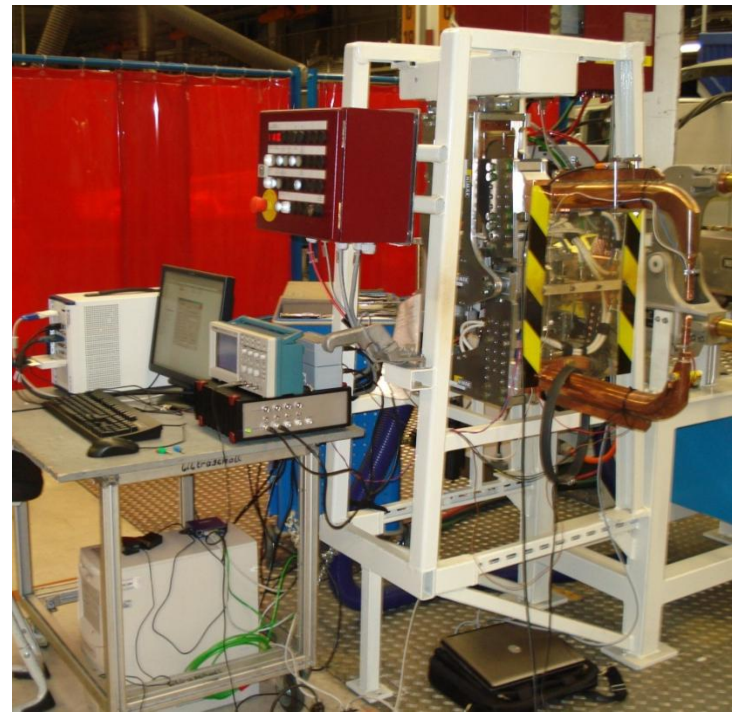
Objectives

- ➔ Implementation of an inline quality control system
- ➔ Obtain a statement for quality of connection and the reached cross-section area of the resistance spot welds
- ➔ Combining different sensor systems in order to gain more information about the process during welding
- ➔ Use of supervised learning procedures for the classification of in-process data and unsupervised procedures for feature detection to optimize classification accuracy

Experiments

Technical equipment and material

- Servo pneumatic driven X-welding gun (NIMAK) with a medium frequency-welding control unit (Bosch)
- Observed process parameters:
  - Welding current
  - Voltage
  - Electrode force
- Combination of
  - Galvanized steel H340LAD Z100 (thickness 1.5 mm)
  - Hot form steel 22MnB5 (thickness 2.0 mm, uncoated)

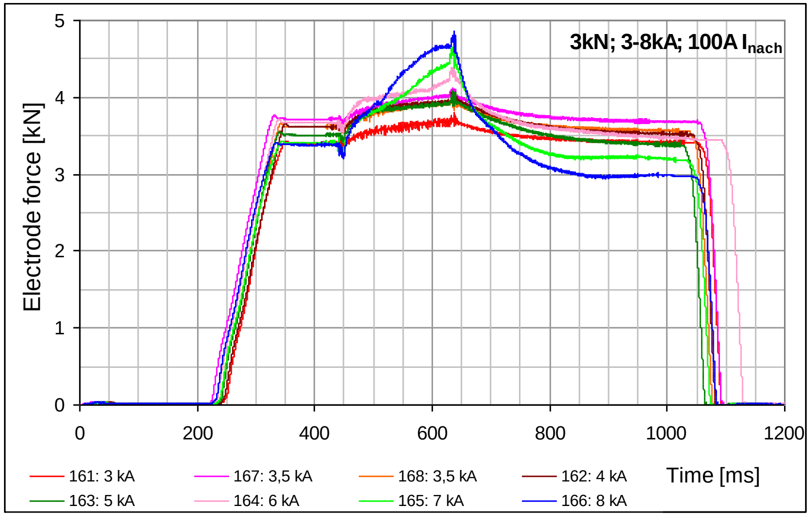


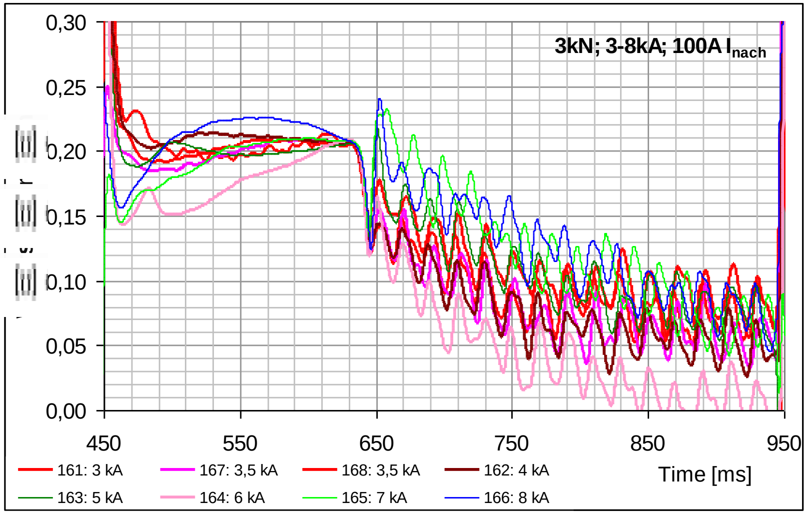
Source: VW Sachsen GmbH, Mosel

Test procedure

- Welding current was varied in the range of {5, 6, 7, 9} kA at an electrode force of 5 kN
- Electrode force was varied in the range of {3, 5.5} kN at a welding current of 6 kA
- At least 10 welds were made under each condition
- Destroying material testing by preparation of metallographic sections for each weld
- Required nugget diameter ≥ 4.3 mm

- Resistance and electrode force waveforms:





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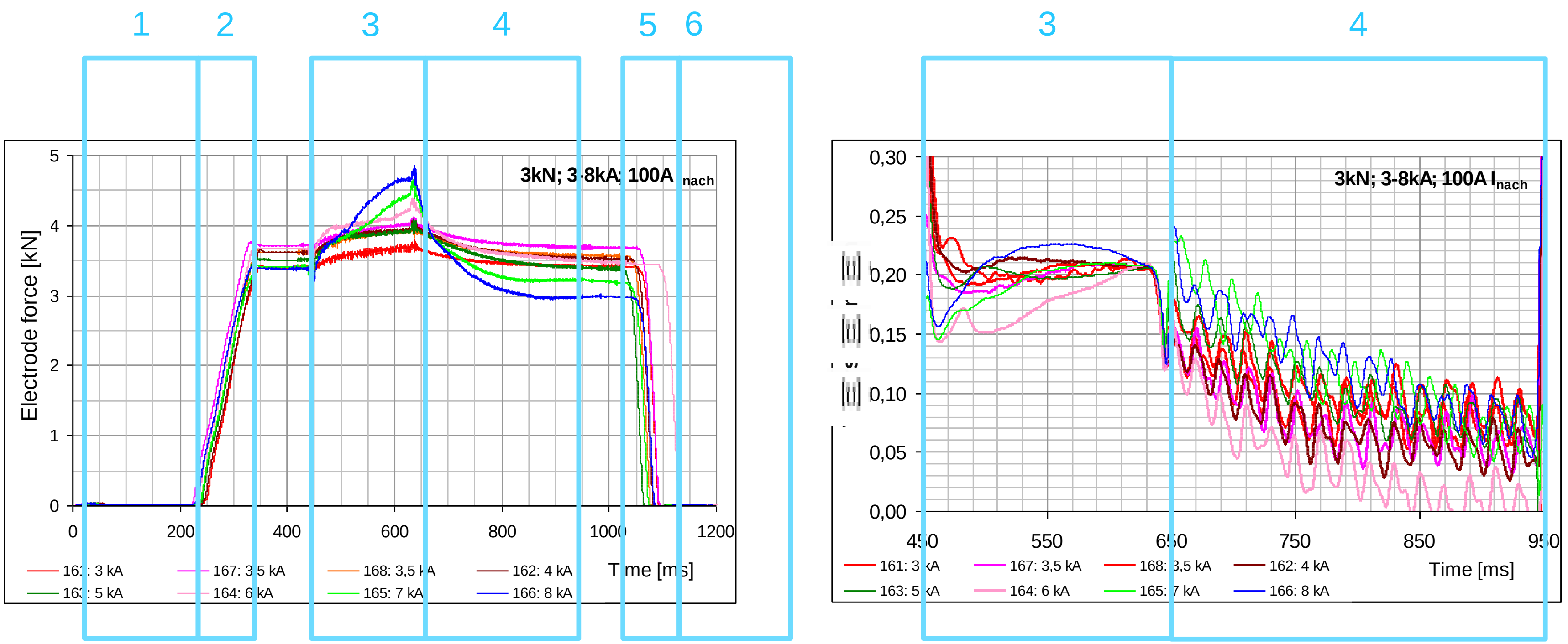

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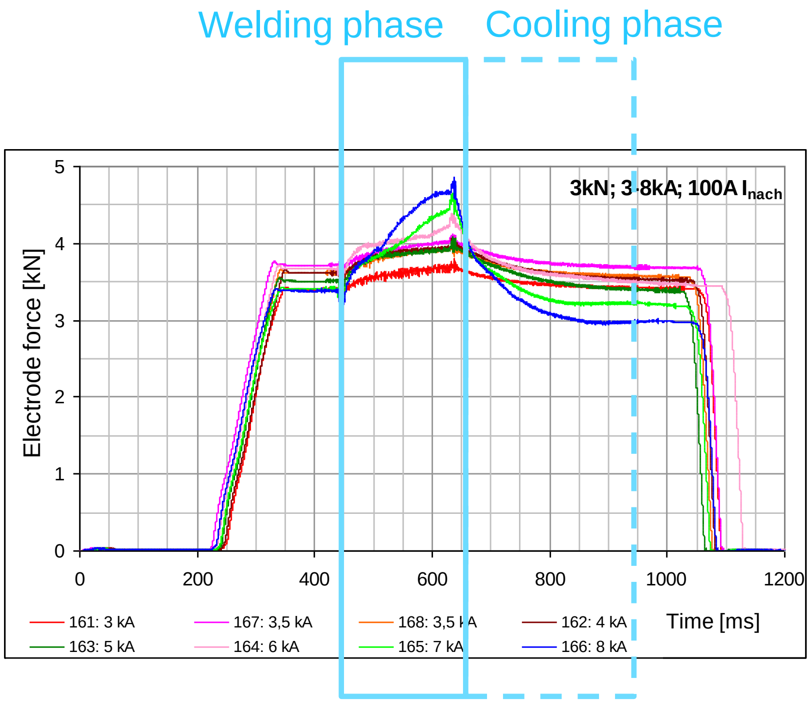
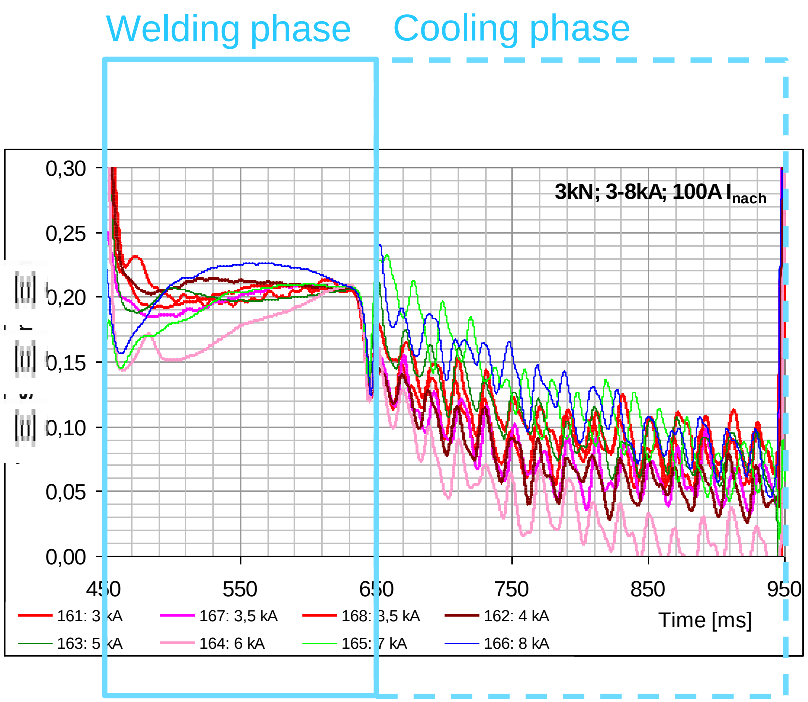
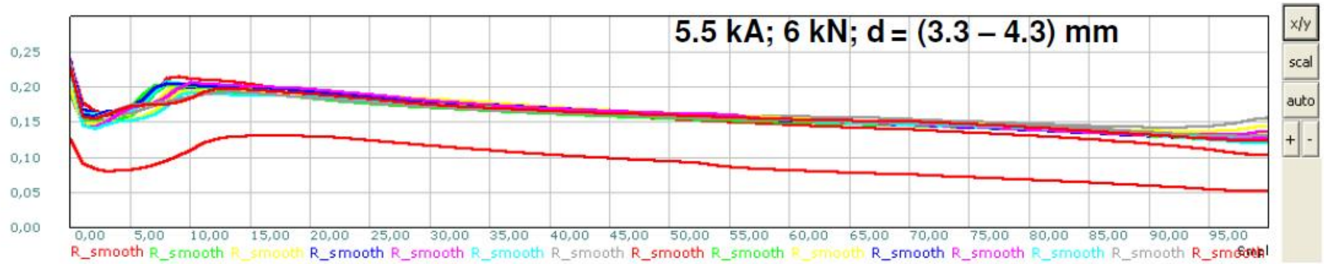
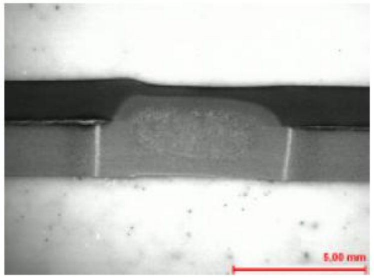
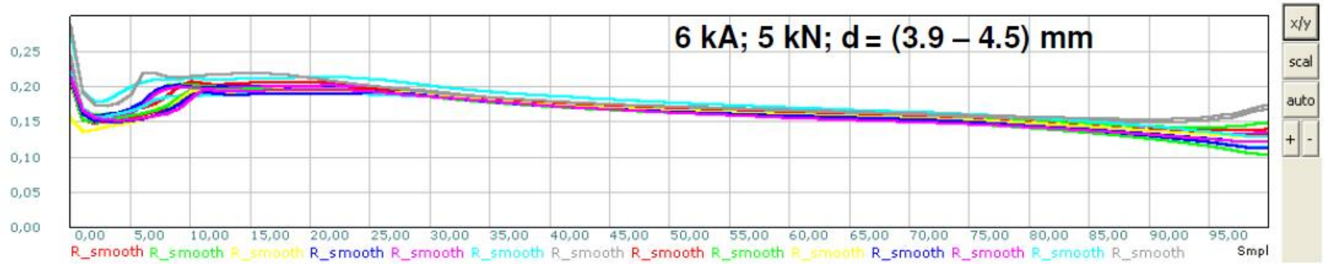


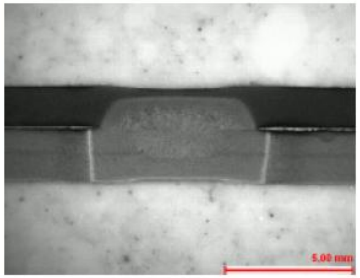


- Resistance waveforms during spot welding with insufficient nugget diameter (d < 4.3 mm):

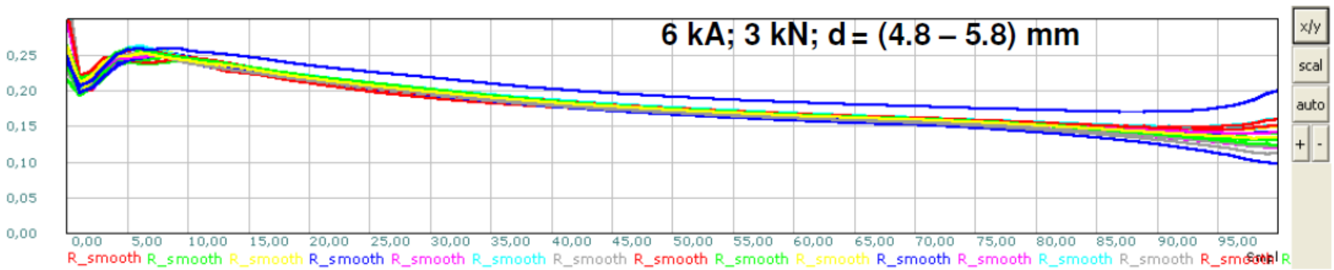


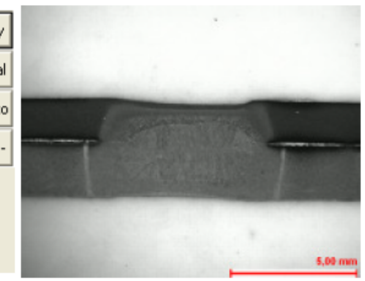


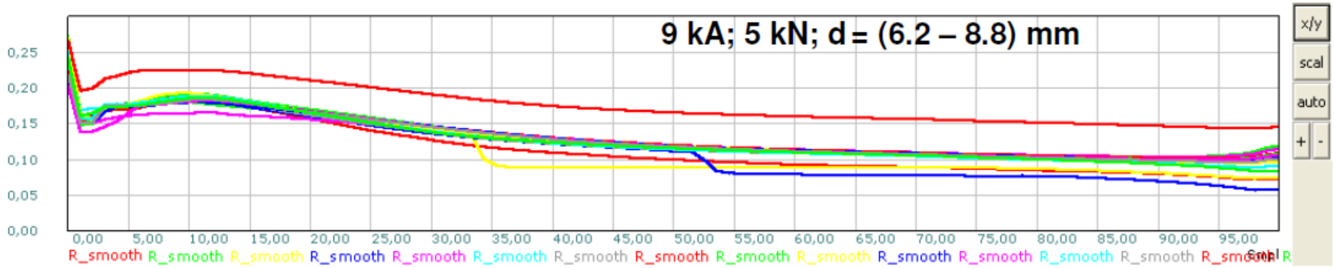


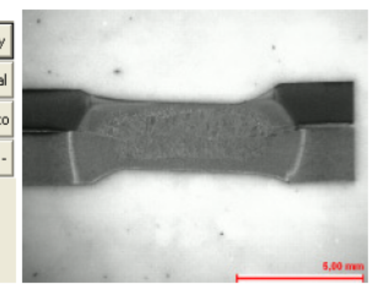


- Resistance waveforms during spot welding with sufficient nugget diameter (d >= 4.3 mm):









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Methods of data analysis

Analysis of In-Process data (overview)

1. Resistance and electrode force waveforms as combined input vectors
2. Reduction of sample number by low-pass filtering
3. Selection of a representative learning set
4. Application of ICA (independent component analysis) to the learning set for feature extraction
5. Training of a MLP-classifier using the determined feature set
6. Testing of the trained MLP using a k-fold cross validation scheme

Feature Extraction

- m ... number of waveform samples (combination of resistance and electrode force values)
- $B \subset \mathbb{R}^m$ contains example waveforms with and without defect characteristics
- For a waveform $s \in B$ the features $f = (f_1 \dots f_n)^T$ with $n < m$ are determined using the linear approach:

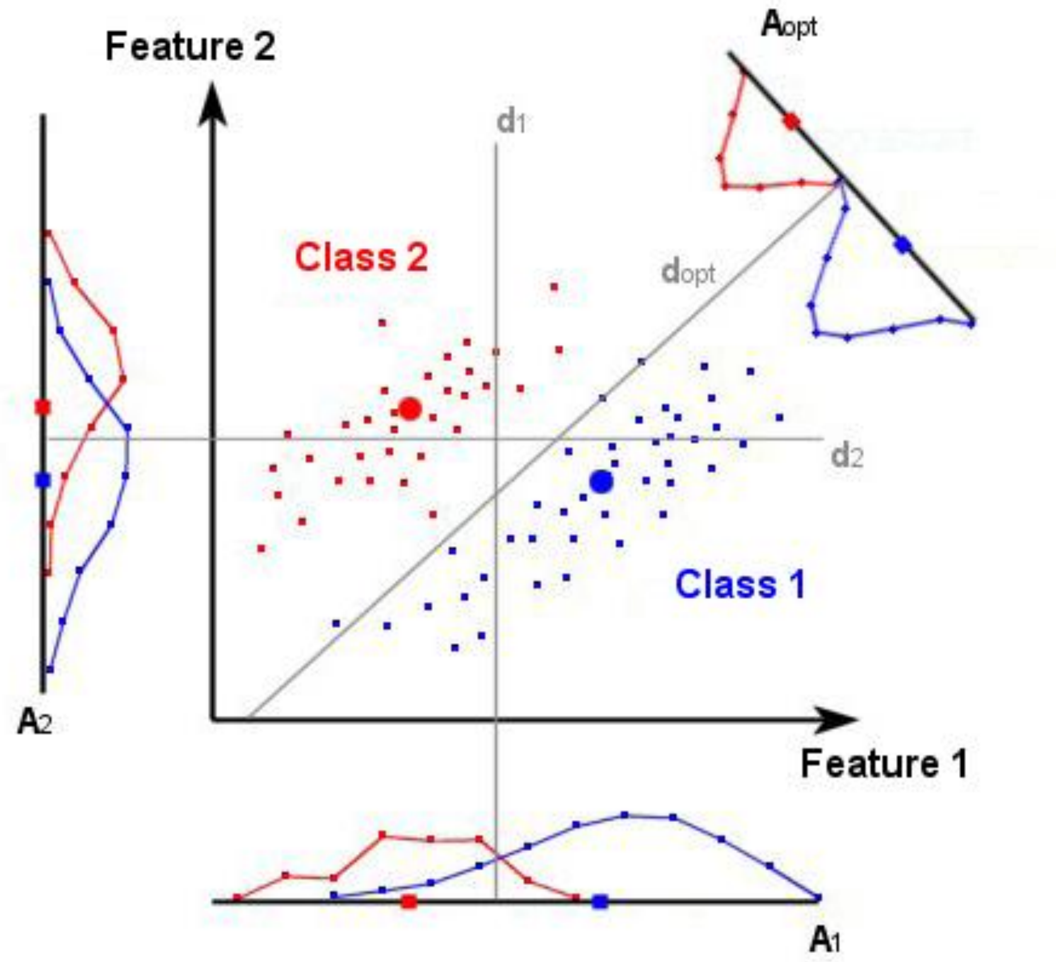
$$f = Cs, \; C \in \mathbb{R}^{n \times m}$$

- An important criterion for the calculation of C is class separability

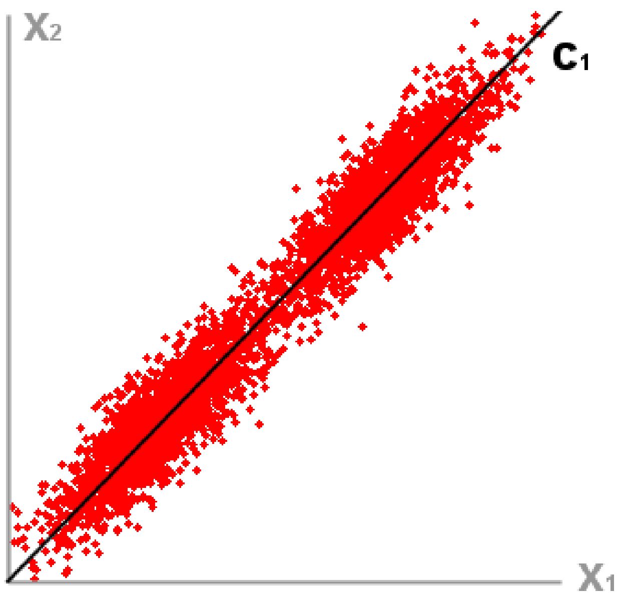
- Separability of classes using LDA:
  - E.g. optimization using a discriminant criterion:

$$\Gamma = \frac{D_{between}}{D_{in}} \rightarrow max$$

  - Problem: Approach assumes normally distributed classes



- Separability of classes using PCA features:
  - $c_1 = \arg max_c E\{\langle c, \xi \rangle^2\}$
  - $c_k = \arg max_c E\left\{\left\langle c, \xi - \sum_{i=1}^{k-1} \langle c_i, \xi \rangle c_i \right\rangle^2\right\}$



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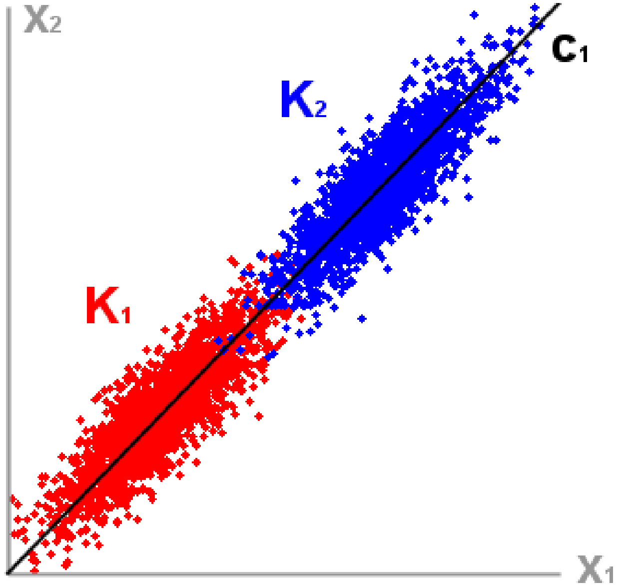
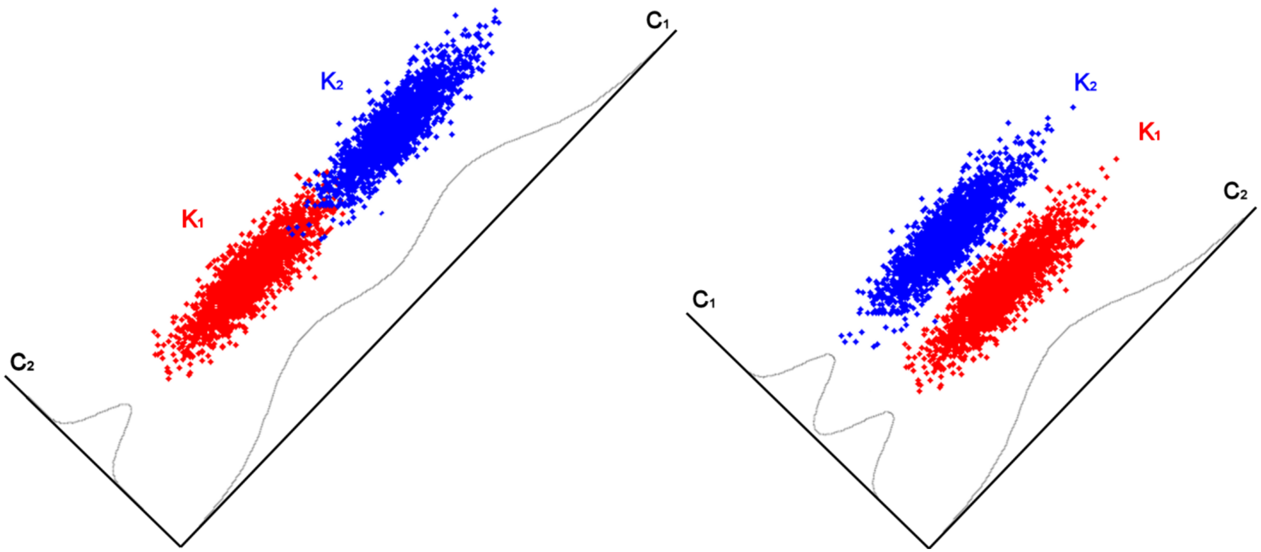


- Principle of ICA:
  - $f_i = \langle c_i, s \rangle$, c_i i-th row of C
  - Waveforms $s \in B$ depend on several observation of welding processes
  - Model waveforms $s \in B$ as random vector ξ and features as random vector η:

$$\eta_i = \langle c_i, \xi_i \rangle$$

  - Try to find a C so that $\eta_1, \ldots, \eta_n$ are statistically independent

- Principle of ICA:



Results of in-process data analysis

- It could be shown that the resistance characteristics during welding process deliver information on formation of weld nugget and reached nugget diameter
- 20-fold cross validation: Partition in only 25% training and 75% test waveforms
- Total accuracy using resistance curves only: 94%
- Total accuracy using resistance and electrode force curves: 95%

Thank you for your attention!

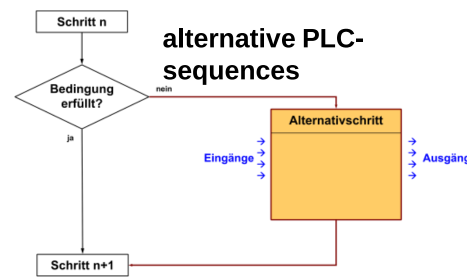
Backup

Department of Automation – core competencies

Process Automation

- Characteristic maps with nonlinear relations / fuzzy logic strategies (error compensations)
- special solutions for controls (replacements and adaptations)
  - multi axes path interpolator
  - compensation strategies, superimpositions of motions
  - process control (combination of different techniques)
- PLC-solutions for
  - structured and optimized sequences
  - fault-tolerant programming methods
- Engineering of complete industrial applications
  - control and drive setup
  - Electrical schematics
  - PLC-programming and NC application programming
  - compensation algorithms
  - synchronized sensor-/ actuator functions

"Virtual Reference Grinding" of a paper dry drum



alternative PLC-sequences

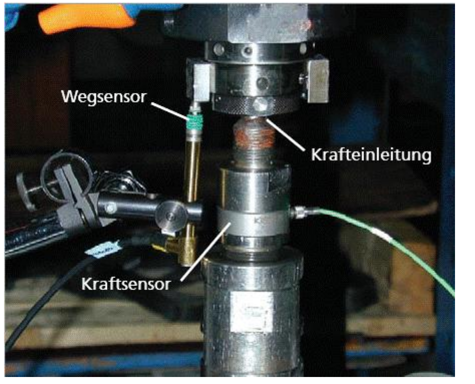
nonstandard press solutions

Department of Automation – core competencies

Analysis and experimental property evaluation

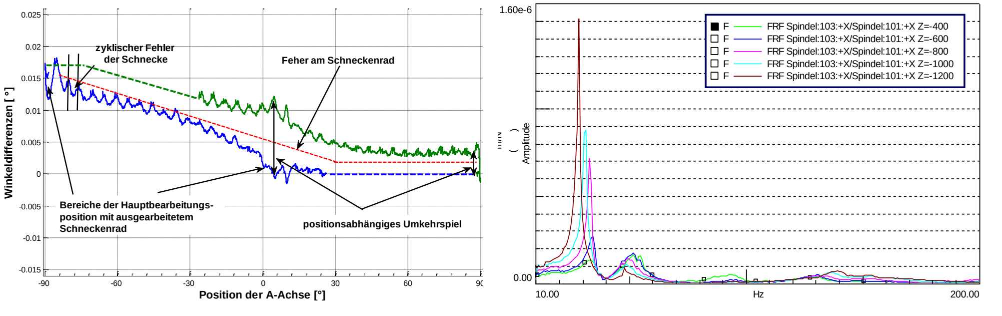
- evaluation of components, machine tools, plants and processes
  - experimental modal analysis
  - static and dynamic compliance analysis
  - vibration analysis during operation
  - Long term analysis for condition based maintenance

- monitoring of static and dynamic measurements
  - compliance
  - deviation and accuracy
  - temperature
  - oscillation behavior
  - acoustic noise
  - energy
  - …



force measurement at a machine tool

static accuracy and dynamic compliance



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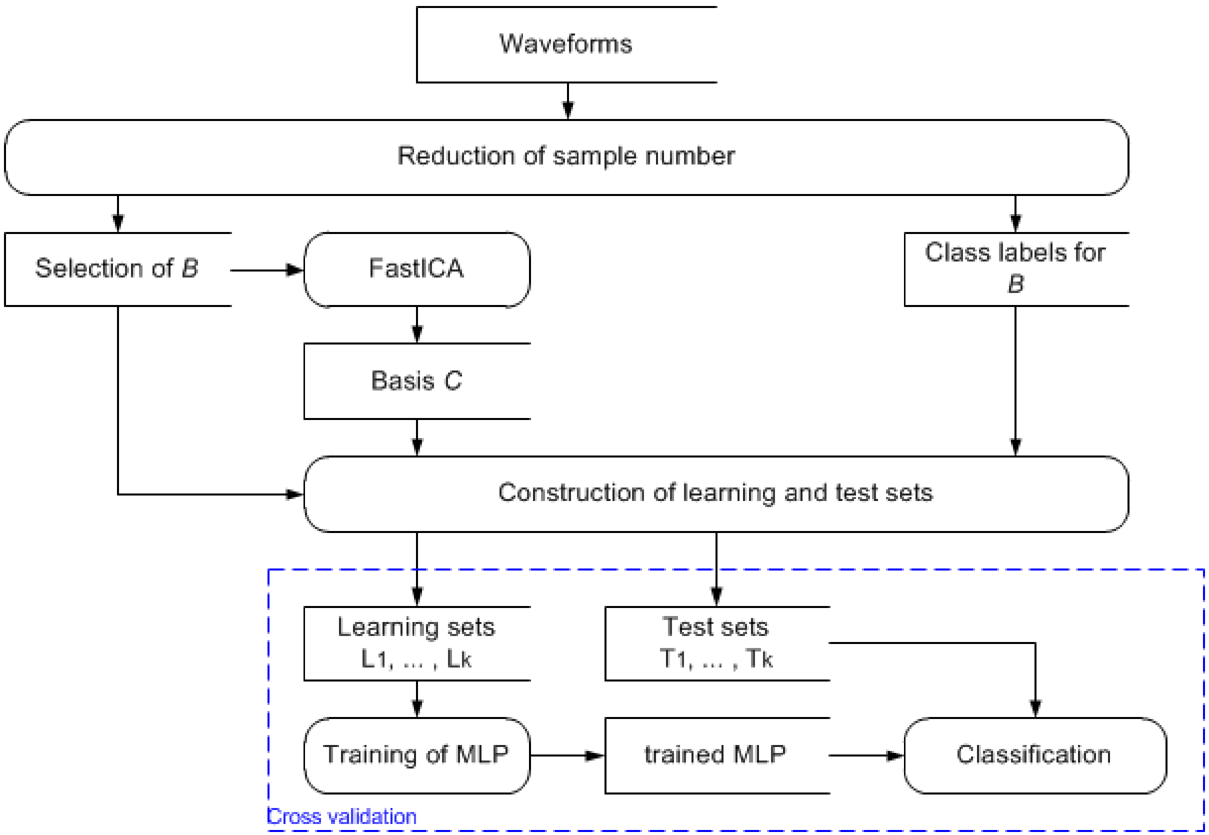
- Data flow diagram for the analysis of in-process data:



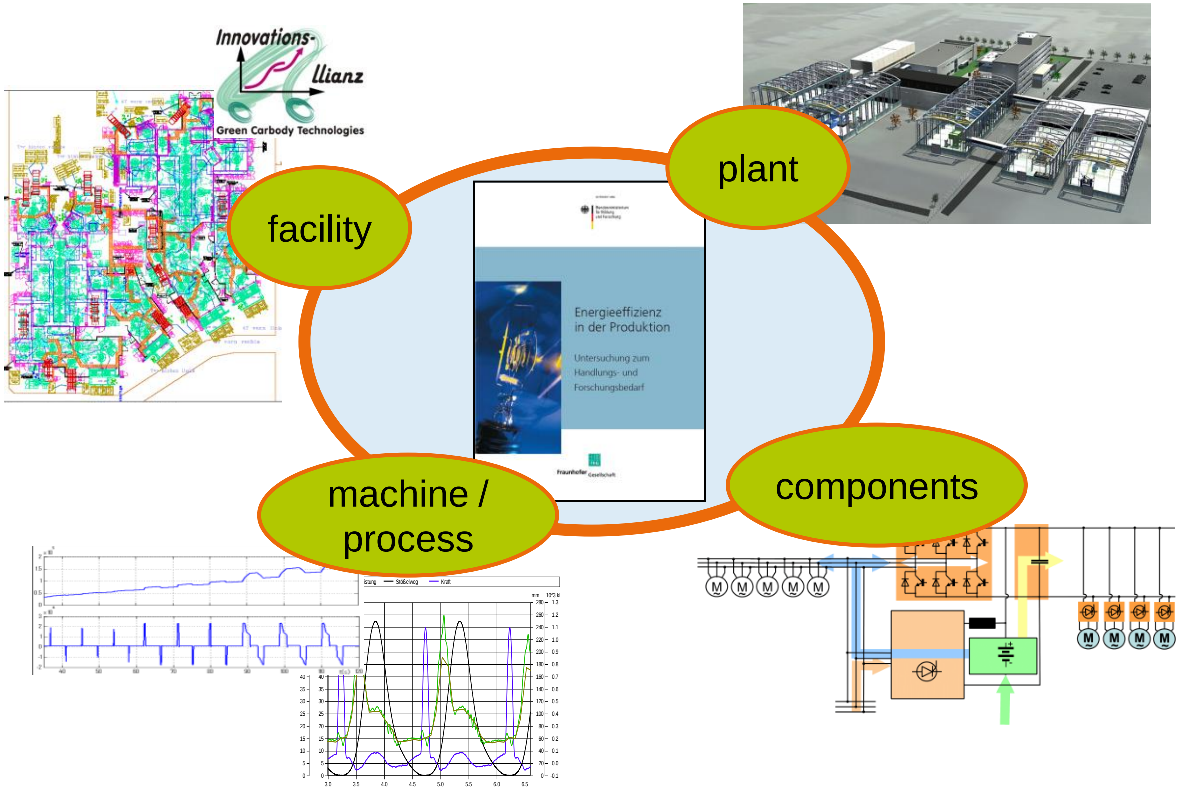
- Principle of ICA:
  - $\eta_1, \dots, \eta_n$ are statistically independent if and only if the corresponding density functions have the property:

$$p(x_1, \dots, x_n) = p(x_1) \cdot \cdots \cdot p(x_n)$$

  - Density functions are unknown → optimization difficult using the above equation
  - Instead maximization of negentropy: $J = H_{Gauss} - H(\eta_1, \dots, \eta_n)$
  - Good approximation (FastICA approach): $J \cong E\{G(\eta_i)\} - E\{G(\eta_i)\}^2$

Department of Automation – core competencies

- **energy efficiency** – a topic with increasing relevance and impact
  - multiple consideration levels
  - measuring and evaluation methods, data handling and visualization
  - conclusions and management



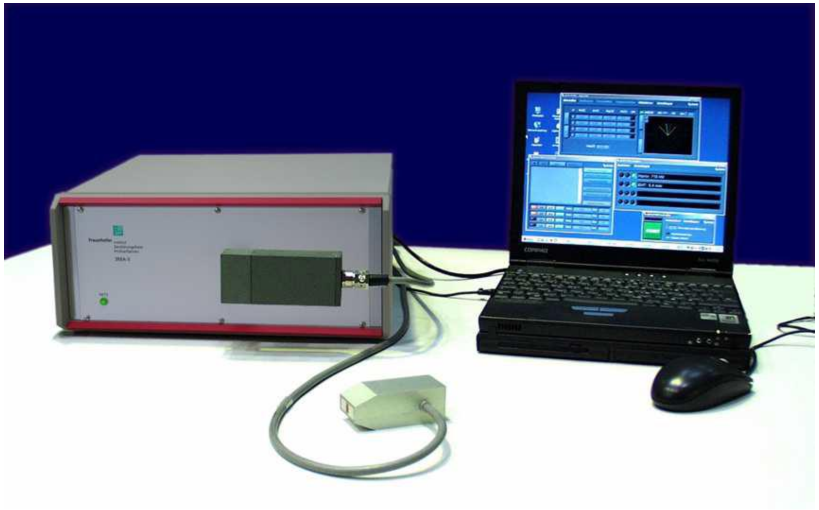
power / energy

- monitor
- evaluation
- Identification of reserves
- process optimization
- energy and resource management
- prediction
- …

Archivierungsangaben

Non-destructively testing via 3MA

- Micromagnetic multiparameter microstructure and stress analysis
- Applicable to ferromagnetic materials only
- Combination of electromagnetic test methods based on altering field magnetization
  - Barkhausen noise, incremental permeability: Waveform provides information on hardness and residual stress
  - Multi-frequency eddy current: Structural changes and defects



TCP-IP-based 3MA equipment and software in combination with a laptop