Method for a Multisensorsystem for In-line Process- and Quality Monitoring of Welding Seams using Fuzzy Pattern Recognition
• Motivation
• State of the knowledge
• Concept
• Results and Conclusions
Motivation

- Quality monitoring is necessary for a stable manufacturing using laser welding
- Different irregularities have to be detected
- Conventional methods which derive from process monitoring are not sufficient

(images by imq GmbH Crimmitschau)
State of the scientific and technical knowledge

Industrial Systems

- Precitec
- Prometec
- Soudronic
- hema electronic
- 4D
- plasmo

Weld Watcher
(4D GmbH)

Formation of a gap (Nd:YAG – Laser)

Molten Mass (CO₂ – Laser)

PD2000
(Prometec)

YW50
(Precitec)

1 1D-Sensor
1 2D-Sensor
3 1D-Sensors
1 2D-Sensor
State of the scientific and technical knowledge

Industrial Systems

- Precitec
- Prometec
- Soudronic
- hema electronic
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- plasmo

Scientific projects

- INESS

Prototype of a multi sensorial process monitoring system with separated data analysis for each sensor system
(Source: BMBF-Project INESS, FGSW, Trumpf, Precitec, DaimlerChrysler, Bosch, Audi, ITO)
Joint Data Analysis

pre-process

in-process

post-process

single analysis

single analysis

single analysis

pre-process signals

in-process signals

post-process signals

joint multivariate data analysis

result / quality management system

Weld Seam OK

Rework

Weld Seam not OK
System Overview

pre-process
- weld seam tracker
- gap detection
- optical detection
- Acoustic Emission

in-process
- EM - emission from laser back reflex
temperature metal vapor
- image processing CMOS, coaxial

post-process
- Eddy current
- surface scanner
- reference methods X-ray thermography

offline verification (NDT)

data analysis
- backward learning

data interpretation and reporting
- parameter
- evaluation of weld seam quality
- trend analysis

system-environment
- peripheral equipment
- robot
- ICT system
  - data handling
  - data storage
  - visualisation

M.Kuhl, Fraunhofer IWU, "IEEE Patras Sept. 2007 IWU.ppt"
Sensor Signals

In-Prozess Emission
- Visible emission
- NIR emission
- Laser back reflex

Video Stream
- Spot - height / length
- Length of molten pool
- Keyhole presence

Surface Scanner

Eddy Current
- Re / Im @ 70kHz
- Re / Im @ 140kHz
**Pre-Conditioner**

- Reference setting
- Date acquisition
- Offset elimination
- Gain adaptation
- Data interpolation / extrapolation
**Feature Extraction**

Data cluster → Filter sets → Feature calculation → Feature values

- derivation
  - min / max
  - average

- statistics
  - average
  - variance
  - standard deviation

- threshold analyses
  - area
  - ratio area vs. length
  - maximal amplitude

- signal comparison
  - min / max
  - average

- complex view
  - location vs. area

- cross correlation

- function generator

- frequency filter

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Feature values:

- \(-0.730837\)
- \(+4.7705\)
- \(+1.311717\)
- \(-0.305882\)
Analysis Tool  Fuzzy-Pattern-Recognition

Idealized graph of a three-dimensional Euclidian Space with 3 separable classes
Analysis Tool  Fuzzy-Pattern-Recognition

\[
\mu(m) = \frac{1}{1 + z(m)}
\]

\[
\mu = \frac{1}{1 + \frac{1}{|M|} \sum_{j=1}^{M} z_j}
\]

\[
z(m) = \begin{cases} 
  m \geq s : & \left( \frac{1}{b_-} - 1 \right) \cdot \left( \frac{m-s}{c_-} \right)^{d_-} \\
  m < s : & \left( \frac{1}{b_+} - 1 \right) \cdot \left( \frac{s-m}{c_+} \right)^{d_+}
\end{cases}
\]

- \( s = \) center point
- \( c_+, c_- = \) class limits
- \( b_+, b_- = \) sympathy value at the class limit
- \( d_+, d_- = \) shape factor
Determination of significant features

Presentation of class separation performance for 5 classes (sympathy value vs. feature value)

Comparison of class separation performance for two features respectively (feature value 1 vs. feature value 2, sympathy value is represented in the hue)

"Try and Error" → Expertise
Computer aided ↔ e.g. Discriminant analysis
Backward Directed Learning

- Surface scanner is not necessary after training step 2
- Sensors, which are not sufficient for industrial applications can be used for training purposes (e.g. x-ray)

- Reduction of learning time
- Reduction of setup costs
Backward Directed Learning

Strong significant Surface Scanner

Low significant Eddy Current Signals
Results and Conclusions

- Techniques of multivariate analysis and the use of several pre-, in- and post-process sensor signals can bring a clear improvement in prediction of faults
- A well considered extraction of significant features is necessary
- Backward directed learning can minimize learning time and setup costs
- The technique is usable for all kinds of similar applications
Thank you for your attention!