Classification and Key Feature Extraction for Equipment Health Monitoring in Plasma Etching

GMM Fachgruppe 1.2.3. – Abscheide- und Ätzverfahren

Christopher Krauel

Fraunhofer Institute for Integrated Systems and Device Technology

Fraunhofer IISB

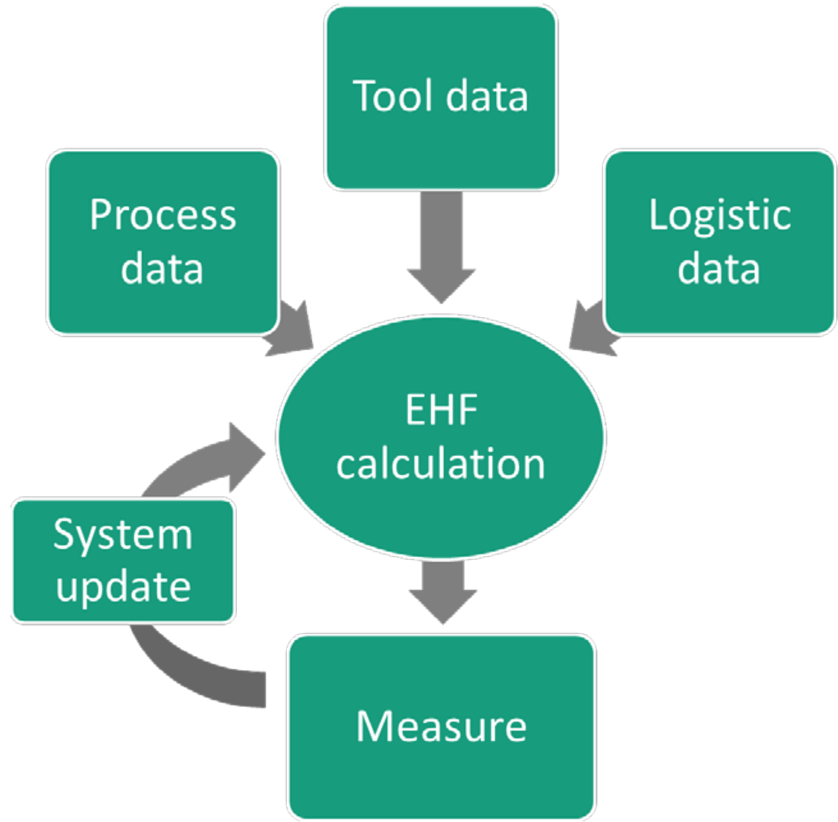
Outline

I. Motivation
II. Classification of curve shapes
III. Key feature extraction
IV. Application examples
V. Further steps for EHF calculation
VI. Conclusion

I. Motivation

Definition: Equipment health factor

- Key indicator for monitoring of equipment state
- Based on process/tool, logistic and metrology data
- Utilization of historical data for training of EHF system
- Related key words
  - Equipment health monitoring
  - Equipment fingerprinting
  - Health index
  - EHF



Goal of the EHF application is to enable…

- **Dynamic Sampling**

  Sampling rate is flexible and adjusted to the machine state.

- **Material flow of critical products**

  The production of critical products (important customers lots, urgent jobs, etc.) is planned only on machines which have a good system state.

- **Predictive Maintenance (PdM) based on condition monitoring**

  The PdM offers cost savings over time-based preventive maintenance, because maintenance actions are performed only when necessary.

Instance for EHF application

- Good machine state – EHF is high
  - ➡ Lower lot sampling rate, important lots will preferably be scheduled to run on this machine
- Machine state not ideal – EHF decreases
  - ➡ More frequent lot sampling, important lots might be scheduled to run on another tool
- “bad” machine state – EHF drops below certain limit
  - ➡ Schedule maintenance

Fraunhofer IISB

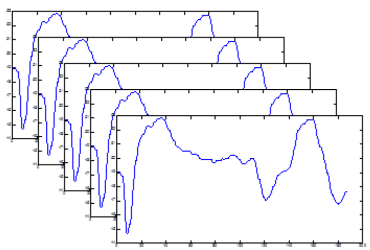
Related work

- Utilization of sensors for simple measurement of wear
- Detection of failures based on key indicators
- Usually only implemented for specific failure classes
- No general method for detection of unknown failures

- **Our objective:**
  - Improved preprocessing method to find unknown failures
  - Use of various feature extraction methods dependent on curve shape
  - Generic concept transferable to other processes

Fraunhofer IISB

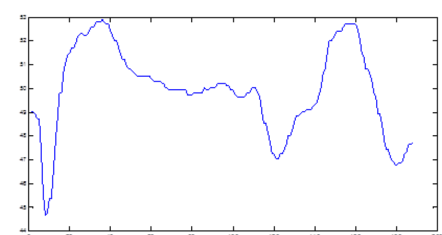
Our approach for EHM



Process variable (time series)

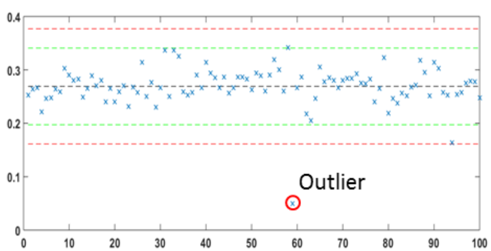
- Oscillating behavior
- Piecewise-constant
- Spike behavior
- Smooth behavior

Classification of curve shape



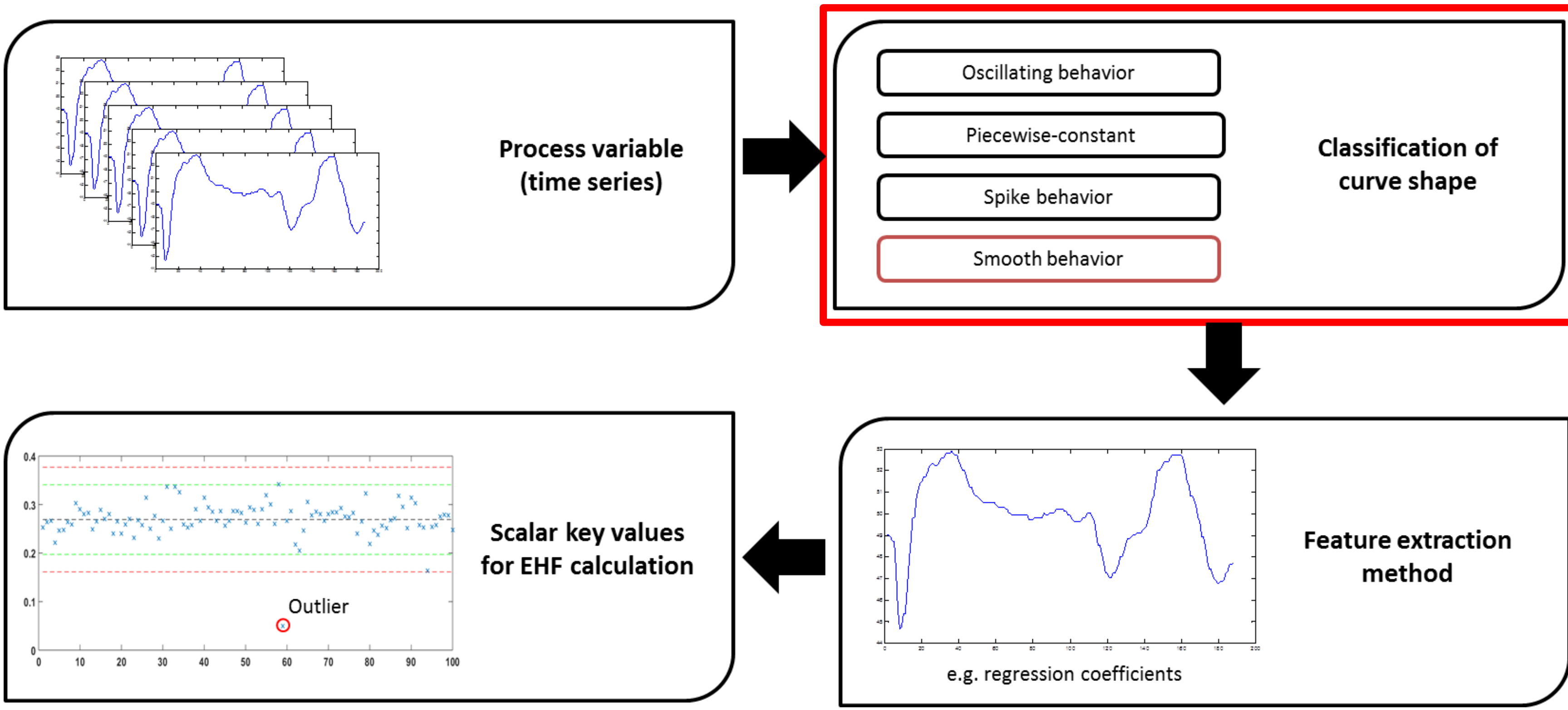
e.g. regression coefficients

Feature extraction method



Scalar key values for EHF calculation

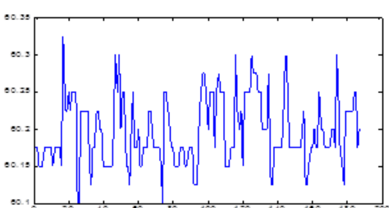
II. Classification



Defined variable types

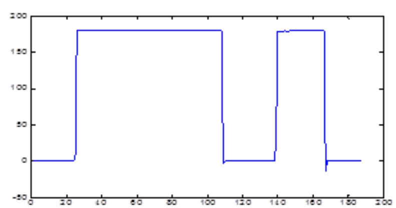
- **Oscillating behavior:** trajectories with periodical variation around a central value
- **Piecewise-constant:** rectangular shaped pulses
- **Spike behavior:** most data points are close to zero with occasional peaks
- **Smooth behavior:** data with little change in their point to point value, the derivation showing only small differences in the gradient

Oscillating behavior



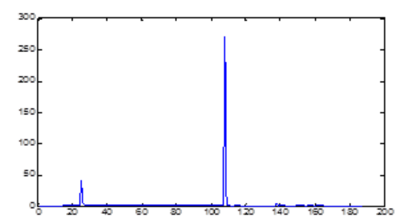
e.g. chamber temperature

Piecewise-constant



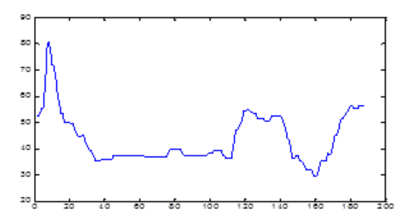
e.g. gas flows

Spike behavior



e.g. reflected RF power

Smooth behavior

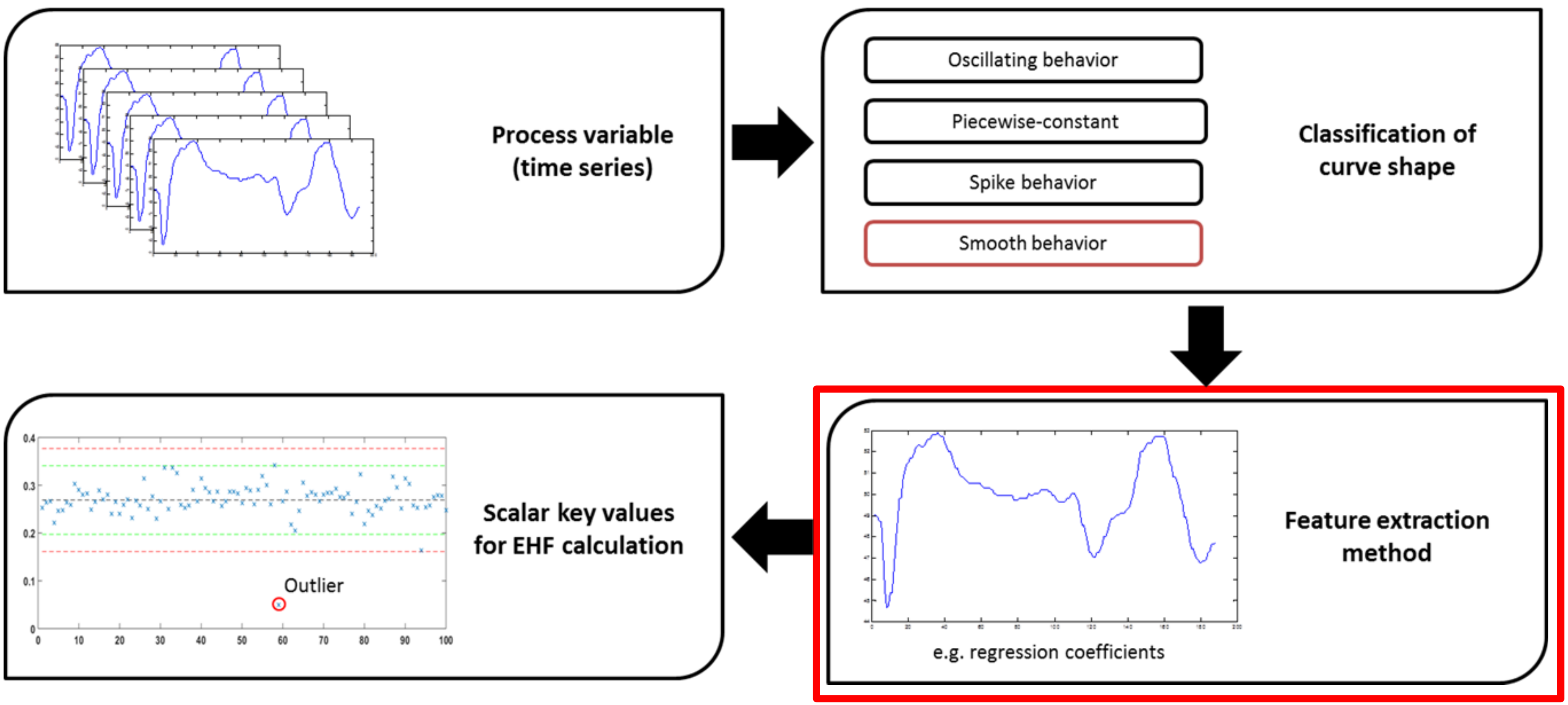


e.g. ESC temperature values

Classification through cubic Support Vector Machine

- Create a training data set containing assignment of variable types
- Cubic support vector machine (SVM) was used
- As predictors were chosen:
    - Kurtosis
    - Crest factor
    - Mean difference of normalized derivation
    - Standard deviation of normalized time series
    - Standard deviation of normalized derivation
    - Logical factor for invariant time series (1 for invariant behavior and 0 for other behavior)

III. Feature Extraction



Types of feature extraction

- **Simple key features**
    - Mean, median, standard deviation and range
- **Structural features**
    - Descriptive statistics of trajectories
- **Dynamic time warping**
    - Euclidean-distance-based similarity measurement technique
- **Frequency and time-frequency analysis**
    - Analysis in frequency domain instead time domain
- **Statistical analytical methods**
    - e.g. regression coefficients or residual analysis

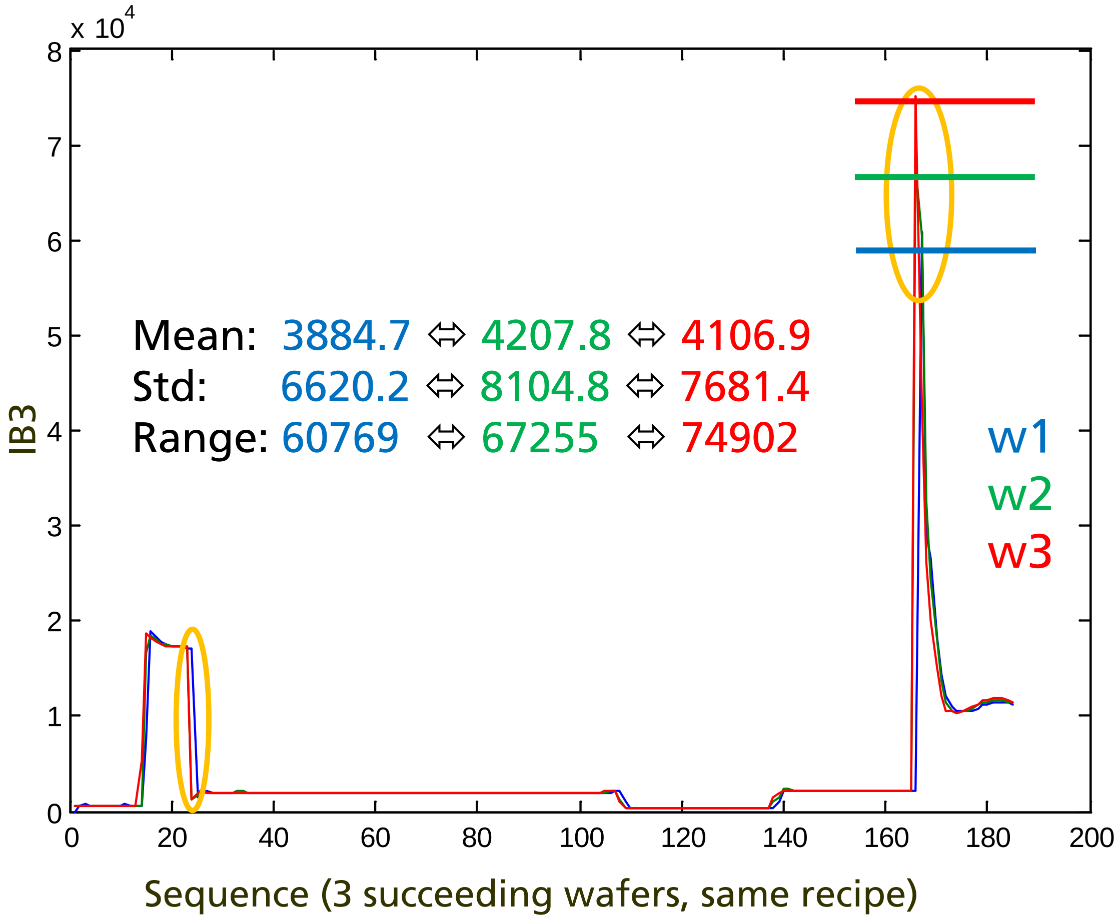
Issues with preprocessing using simple key features

- Over-/undershooting controllers and length of a signal can have big impact on simple key values
- Potential impact of limited data sampling frequency on true transient behavior
- Measurements from etch processes are non-stationary due to:
    - Aging of the etcher after cleaning cycles as residue accumulates on the inside of the chamber
    - Difference in the incoming materials due to changes in upstream processes
    - Drift in process-monitoring sensors themselves

Example for simple key features

Correlation matrix:

	w1	w2	w3
w1	1	-	-
w2	0.7871	1	-
w3	0.6831	0.9802	1



10 December 2015

Fraunhofer IISB

Potential feature extraction methods

Oscillating behavior
- Frequency analysis
- Time-frequency analysis
- Coefficients from time series modeling

Piecewise-constant
- Structural features
- Integration
- Regression coefficients

Spike behavior
- Peak detection
- Structural features
- Integral value of peak

Smooth behavior
- Regression coefficients
- Residual analysis
- Coefficients from time series modeling

Fraunhofer IISB

Extracted features

Oscillating behavior
- Periodicity
- Trend
- Simple key features

Piecewise-constant
- Number of pulses
- Amount of Under-/Overshoots
- Maximum Overshoot
- Surface area of pulse

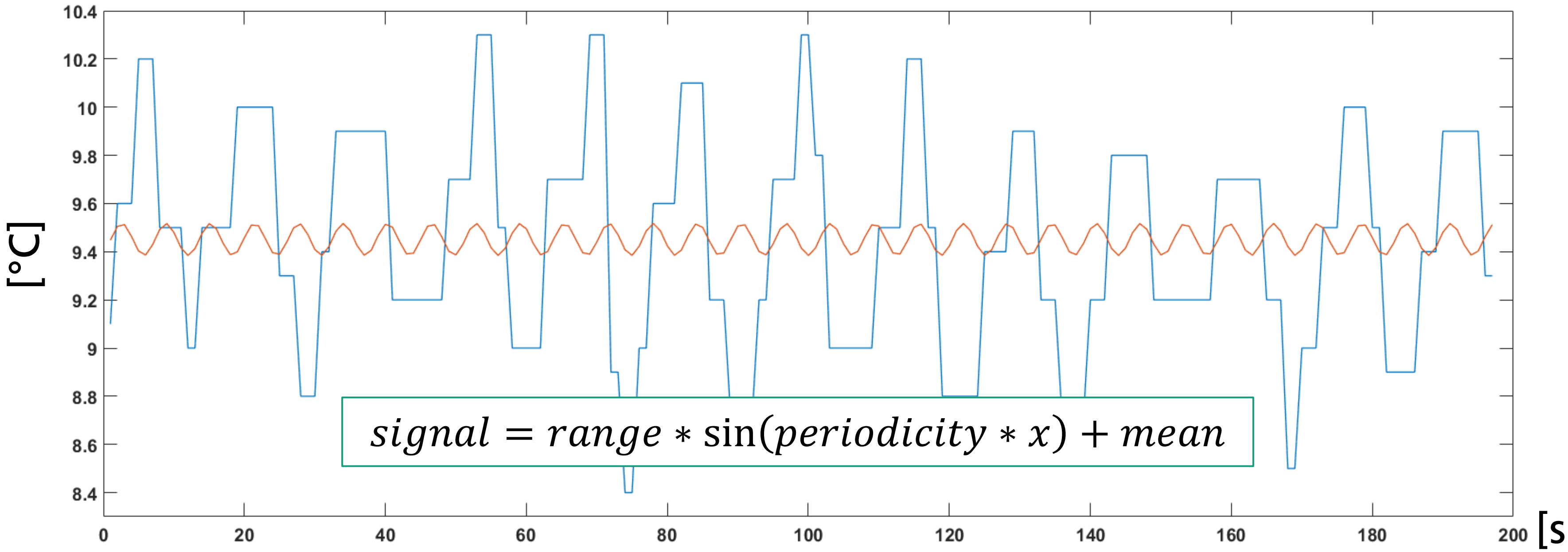
Spike behavior
- Number of peaks
- Peak width
- Surface area of peak
- Distance of peaks

Smooth behavior
- Wavelet-based correlation coefficient
- RMS of residuals
- Surface area

Fraunhofer IISB

IV. Application example 1

Temperature chiller

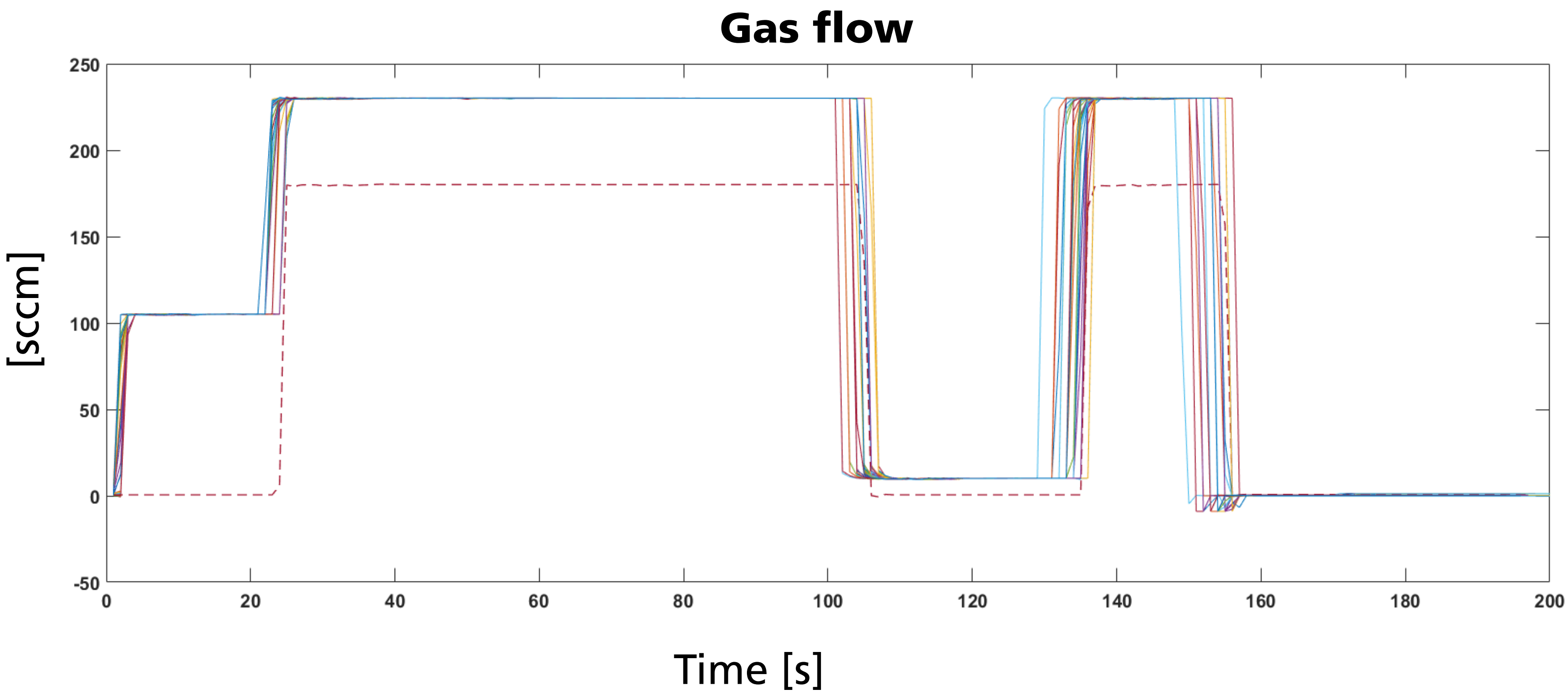


$$signal = range * \sin(periodicity * x) + mean$$

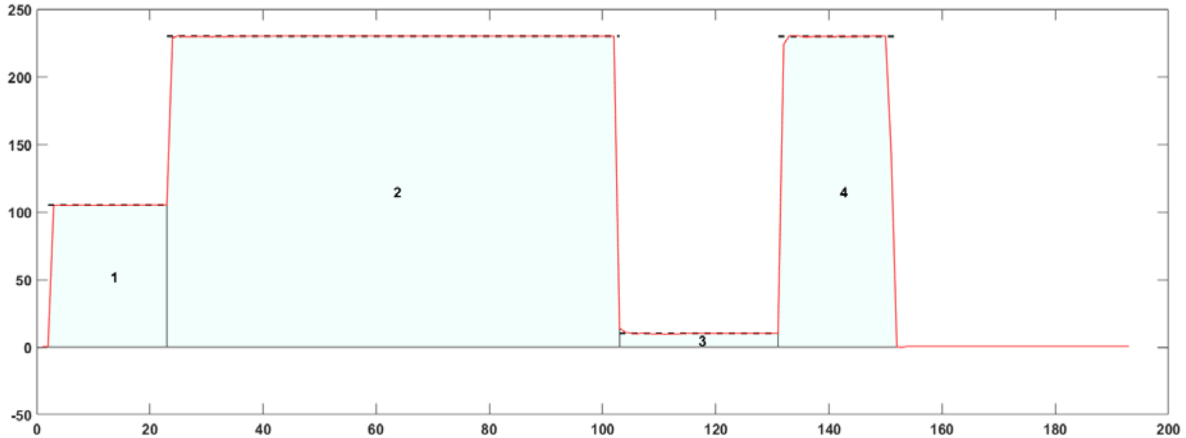
Curve	Mean	Periodicity	Range
Blue	9.4508	15.4763	1.9
Orange	9.4511	6.2733	0.1329

Fraunhofer IISB

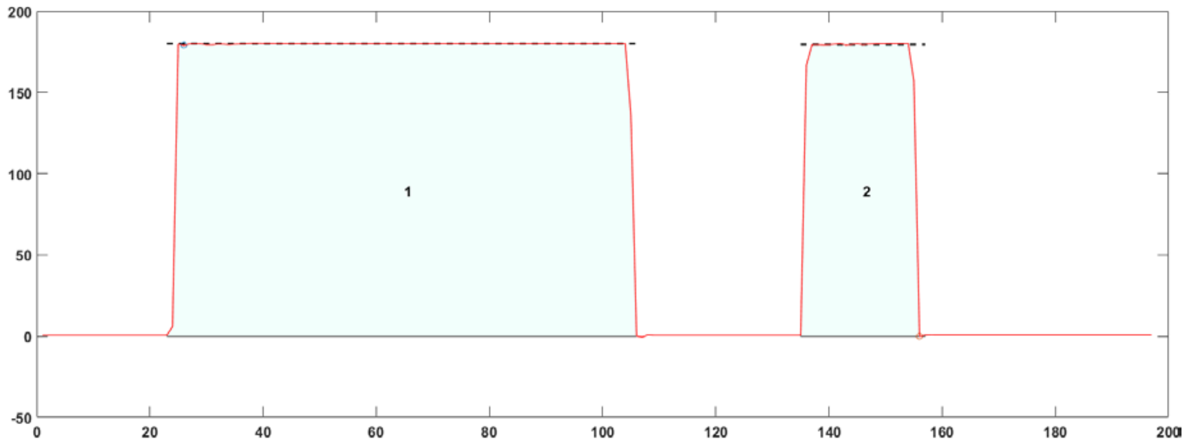
IV. Application example 2 (1/3)



IV. Application example 2 (2/3)
Comparison of two gas flows



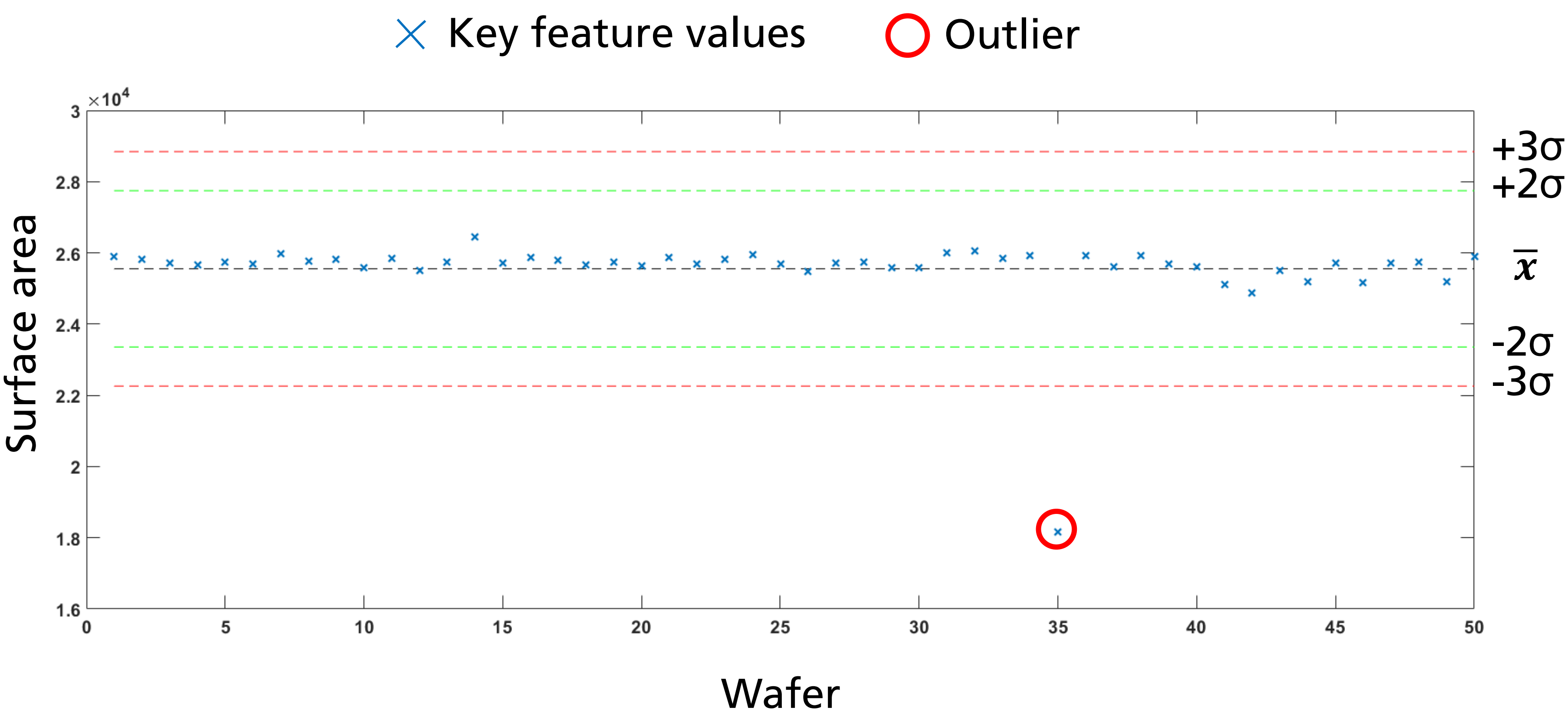
Desired trajectory



Faulty trajectory

Fraunhofer IISB

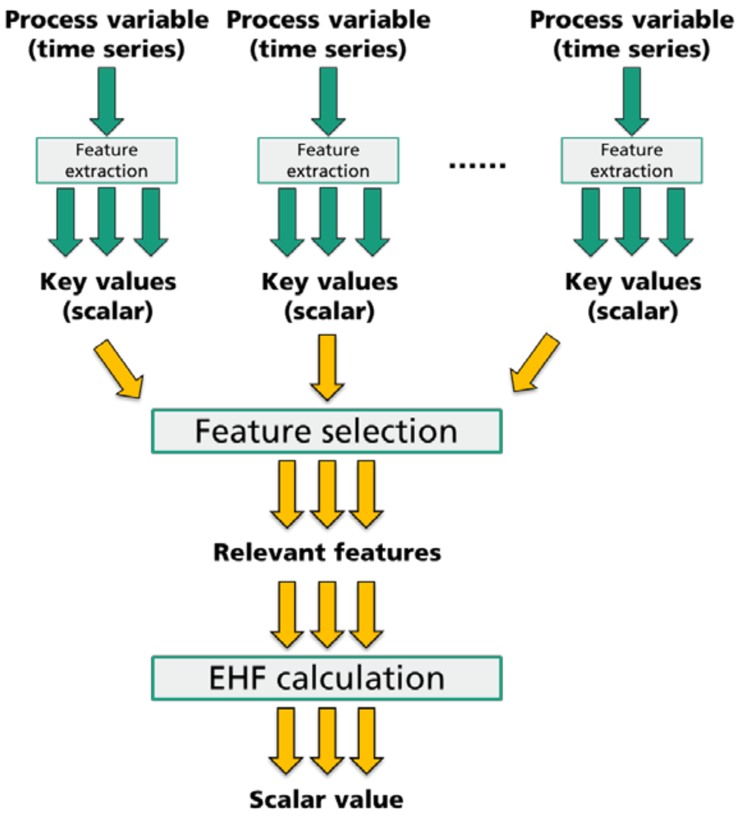
IV. Application example 2 (3/3)
SPC-Chart: Surface Area



Fraunhofer IISB

V. Further steps for EHF calculation

- Feature selection
  - Which features are important for EHF?
  - How to select them automatically?
- EHF Calculation
  - How to combine the relevant key features to a scalar value to express the system state?



Fraunhofer IISB

VI. Conclusion

- A general method for detection of unknown failures was developed
- Generic concept transferable to other processes
- Application of various feature extraction methods dependent on curve shape
- Extracted key features can be used for EHF calculation or other technologies to improve models, e.g. PCA
- Desired benefit of EHF
    - Lower production costs
    - To support Predictive Maintenance
    - Maintaining high yield

Fraunhofer IISB

Acknowledgment

- The development of these EHF methods is a part of the EU cooperative project “Enhanced Power Pilot Line” (EPPL) which is co-funded by grants from Austria, Germany, The Netherlands, France, Italy, Portugal and the ENIAC Joint Undertaking and is coordinated by Infineon.

- WP-Partner:
  - Dresden University of Technology
  - Fraunhofer Institute for Integrated Systems and Device Technology
  - Infineon Technologies Austria AG
  - Infineon Technologies Dresden GmbH
  - SpeedUp Consulting

Fraunhofer IISB

Thank you for listening!