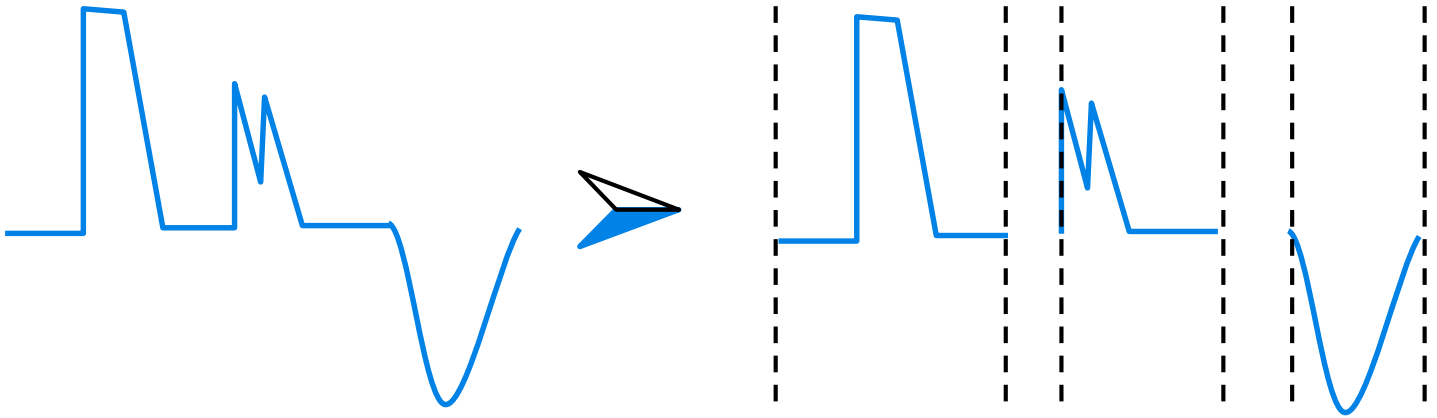

Predictive Maintenance using MATLAB: Pattern Matching for Time Series Data

Dr. Irina Ostapenko (Dr. Türck Ingenieurbüro GmbH),
Jessica Fisch (Daimler AG)

26.06.2018

Collaboration partners

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Jessica Fisch

Mercedes-Benz Werk Mettingen

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Focus:

- Digital Transformation
- Big Data
- IIoT

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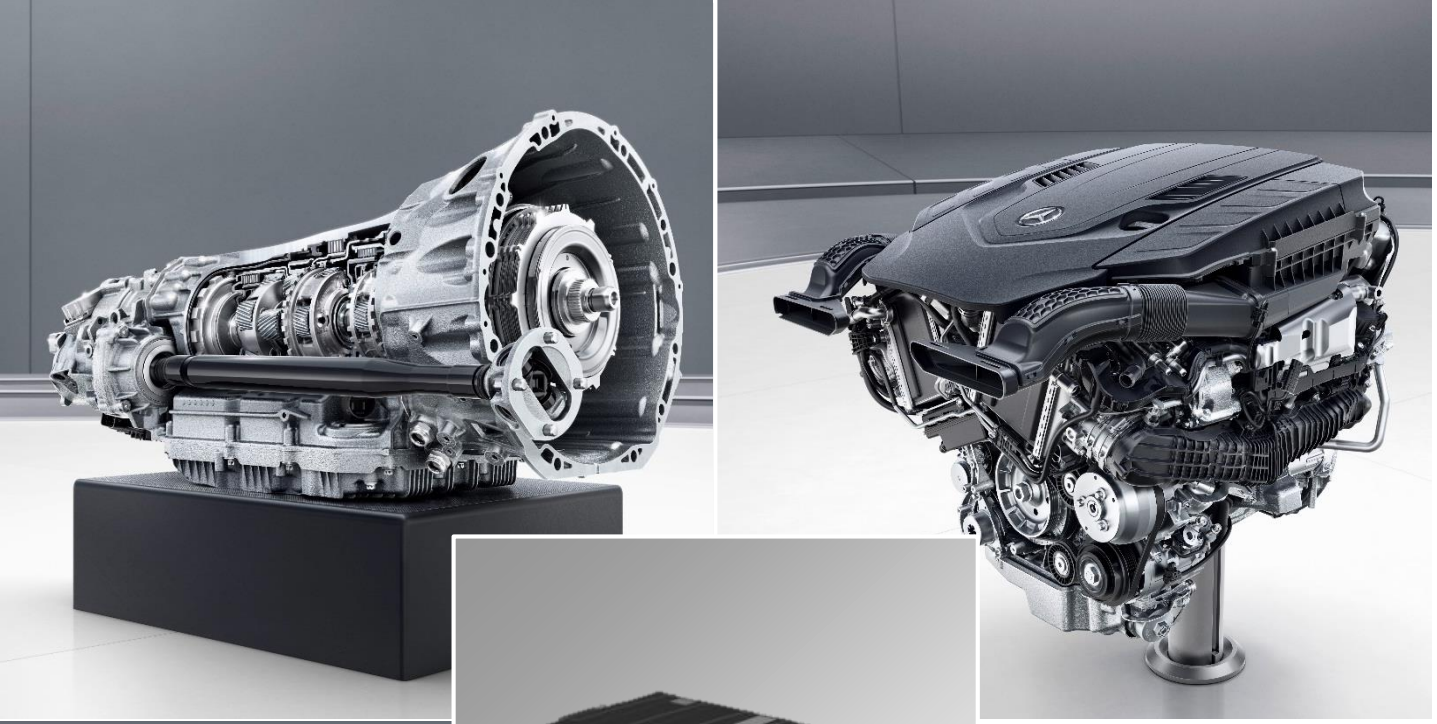
We provide

- Algorithms
- Signal Processing
- Measurement Systems Developing

Optical System Design

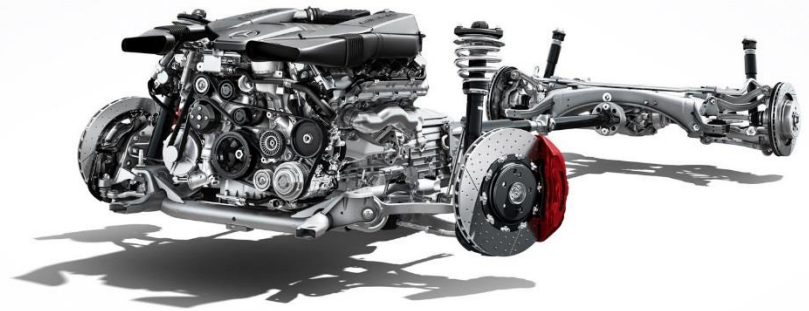
Outline

1. Project introduction
2. Task description
3. Solution/Algorithm
4. Summary



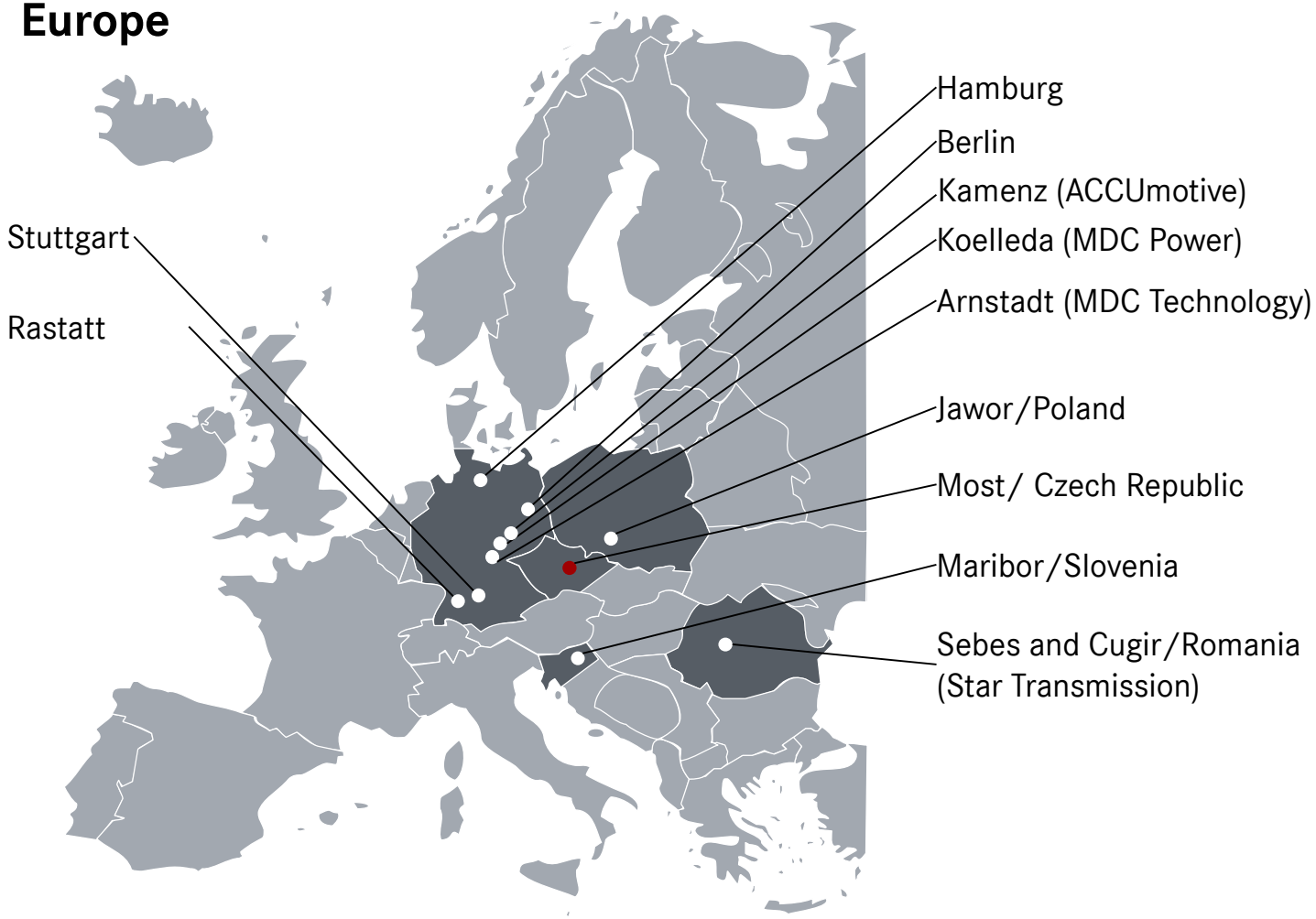
POWERTRAIN

Five modules form
the core of our cars

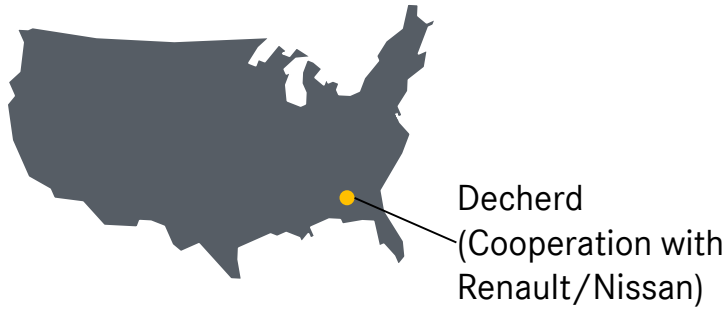


The Powertrain production network is set up globally with lead plant in Germany

Europe



USA



China

Legend

- 100% Daimler
- Majority Holding
- Joint Venture
- Cooperation

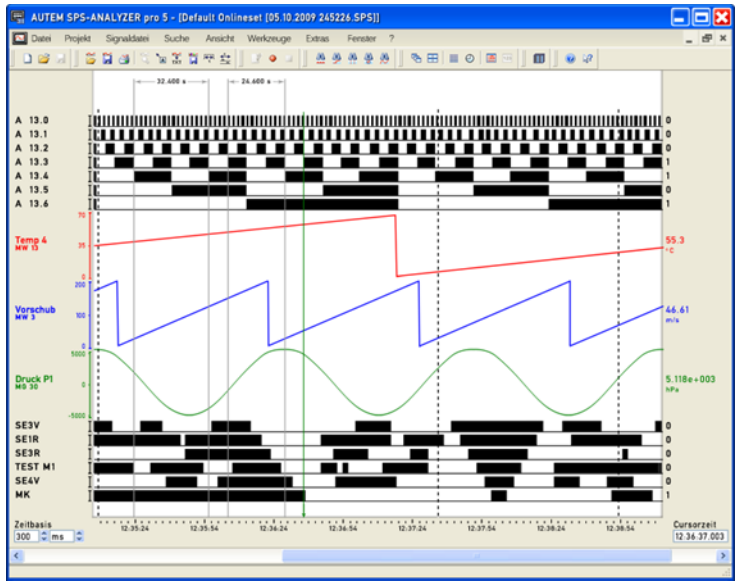
Mercedes-Benz

Dr. Türck Ingenieurbüro
Data Science

Motivation for Anomaly Detection in the Projekt „iLL“

The goal is to detect anomalies in data

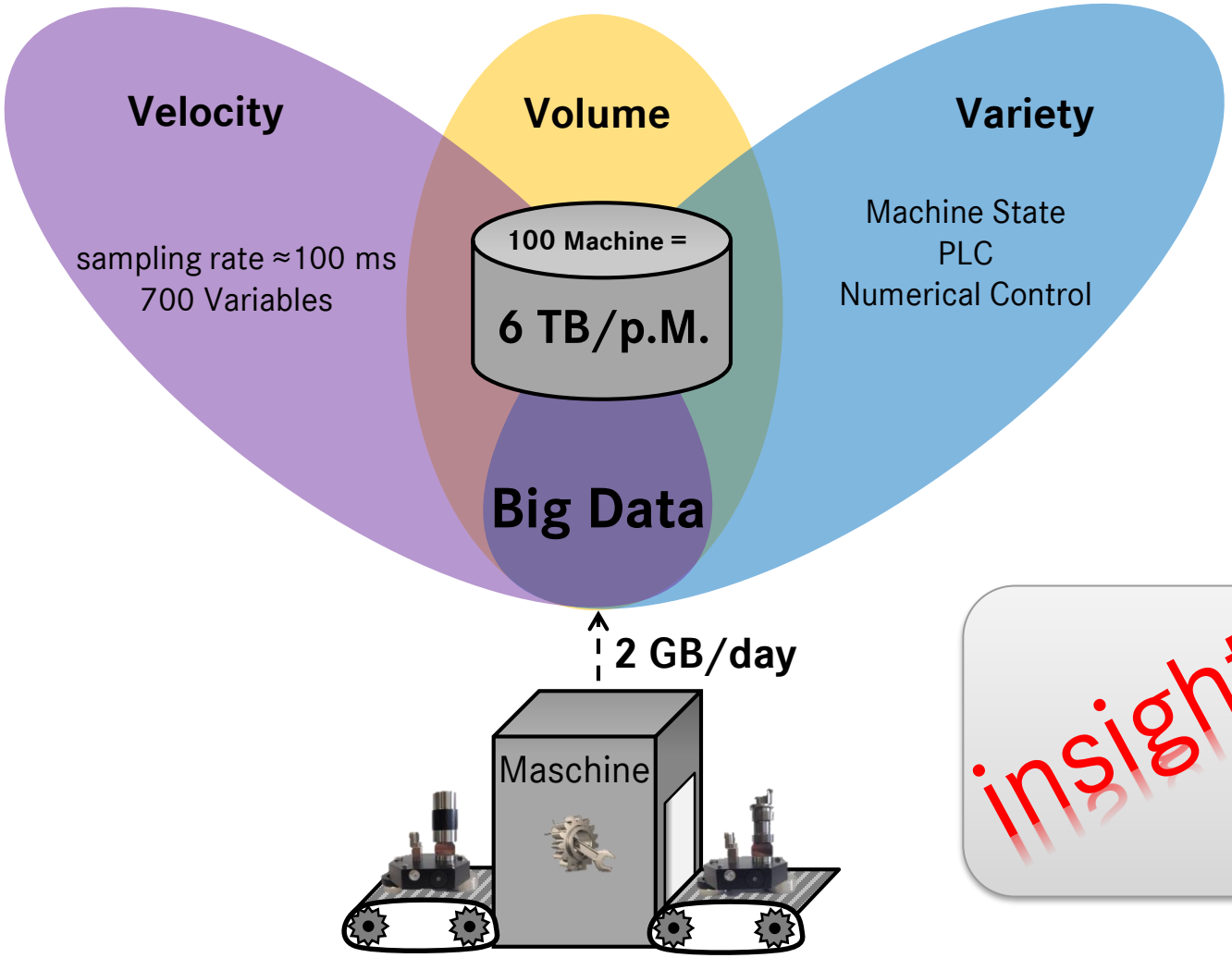
PLC-Data today:



Source: www.autem.de

Automatic Notification of the Deviation:

Data properties in the context of Big Data



The 3 basic V's of Big Data:

- **Velocity**: Speed with which data is generated and analyzed
- **Volume**: Amount of data that traditionally can not be analyzed
- **Variety**: Data diversity refers to unstructured data without a recognizable context

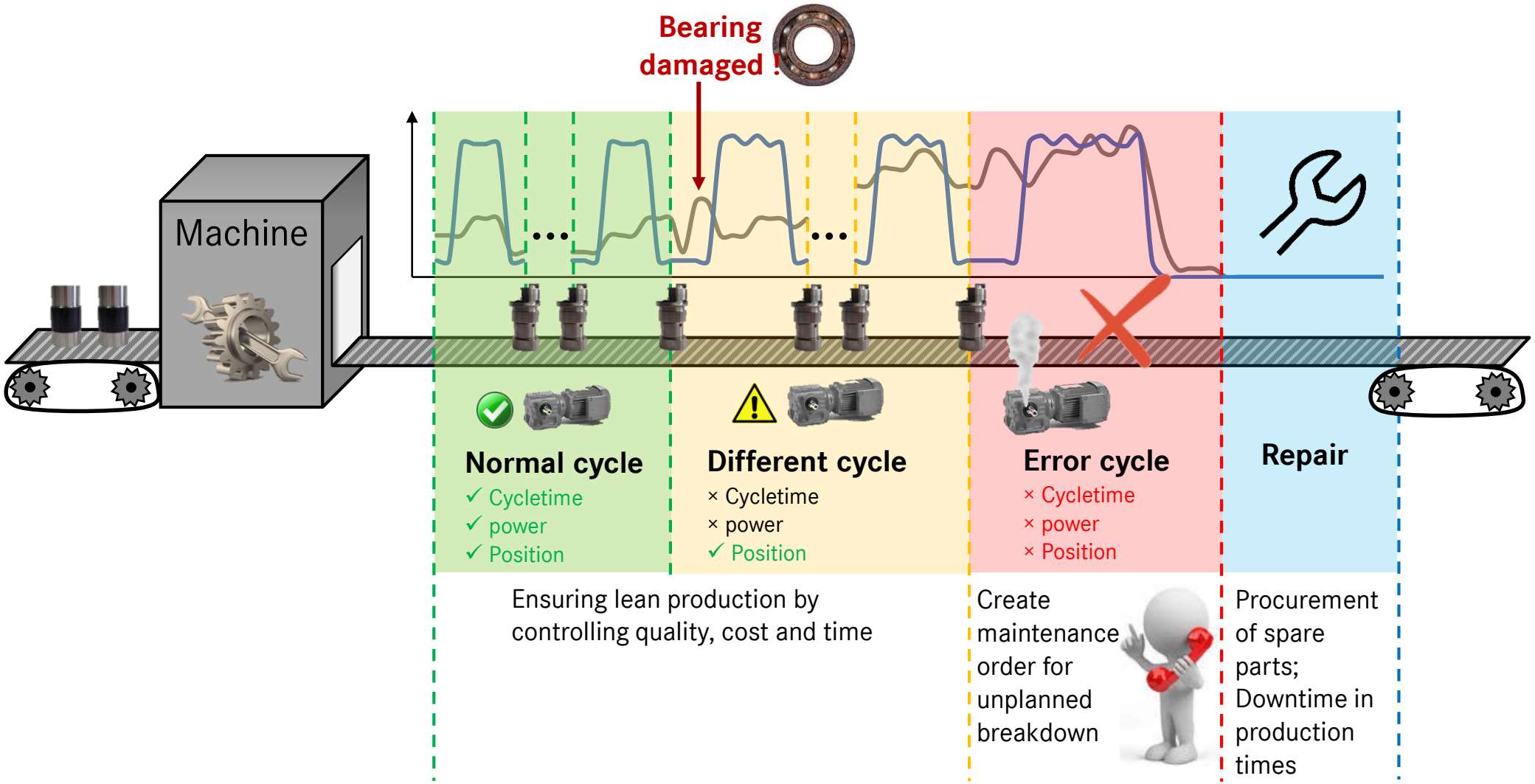
insight

The 2 additional V‘s:

- **Validity**: Ensuring data quality
- **Value**: measurable benefits from the data

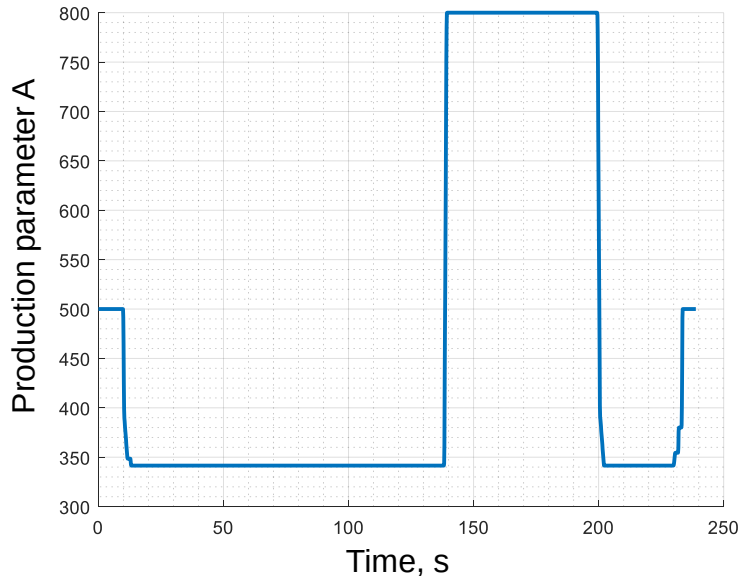
Benefits of „Intelligent Level-Learning“

— Active power engine axis 1
— Position axis 1



Challenges

- About 700 parameters are continuously monitored in every production cycle yielding 700 individual time-series of about 2500 samples each



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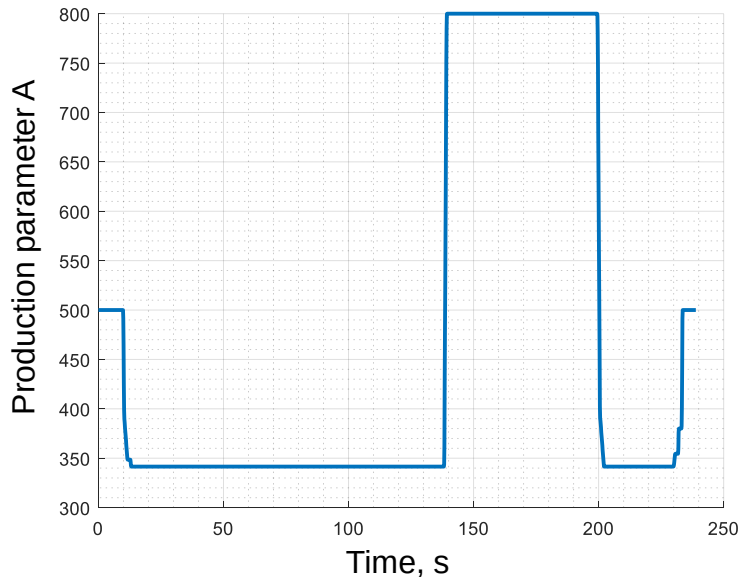
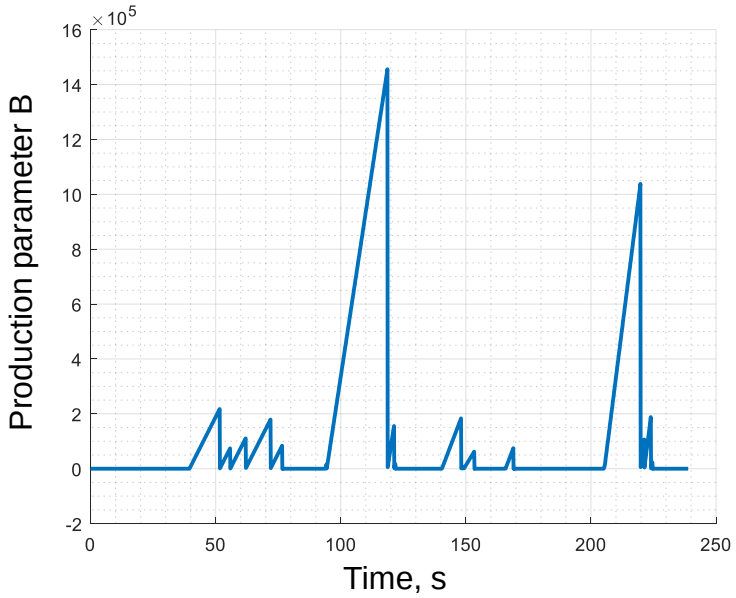
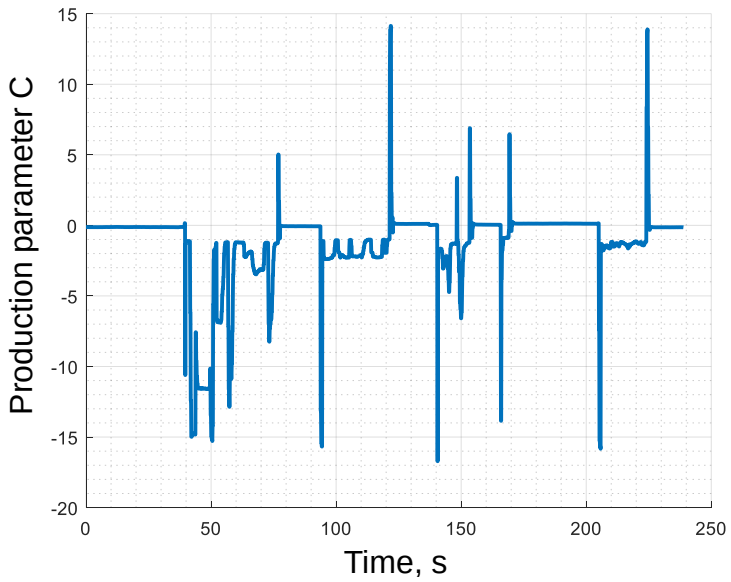


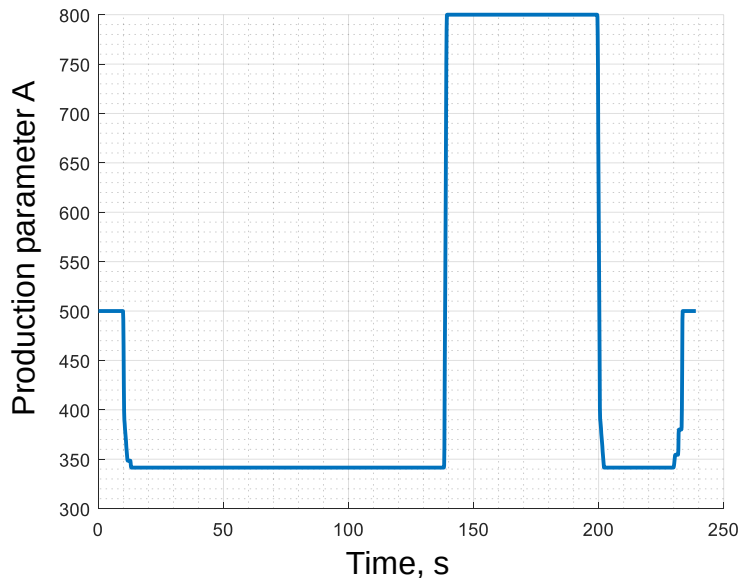


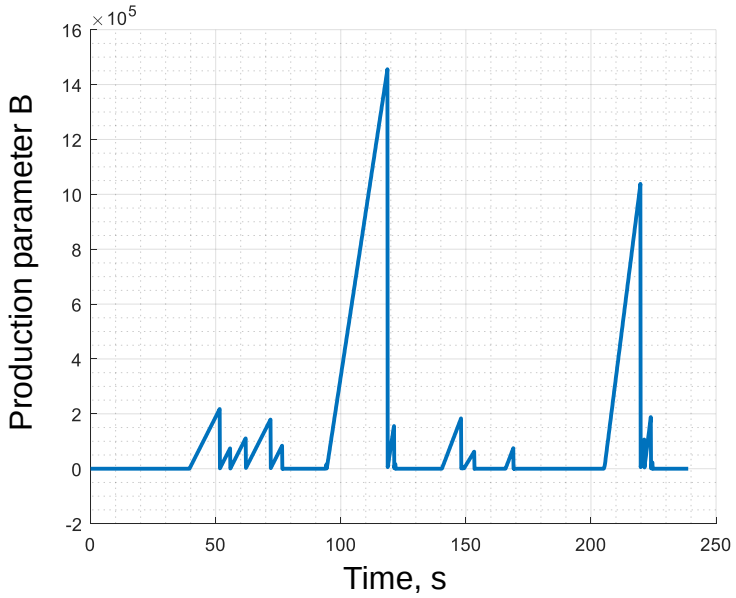


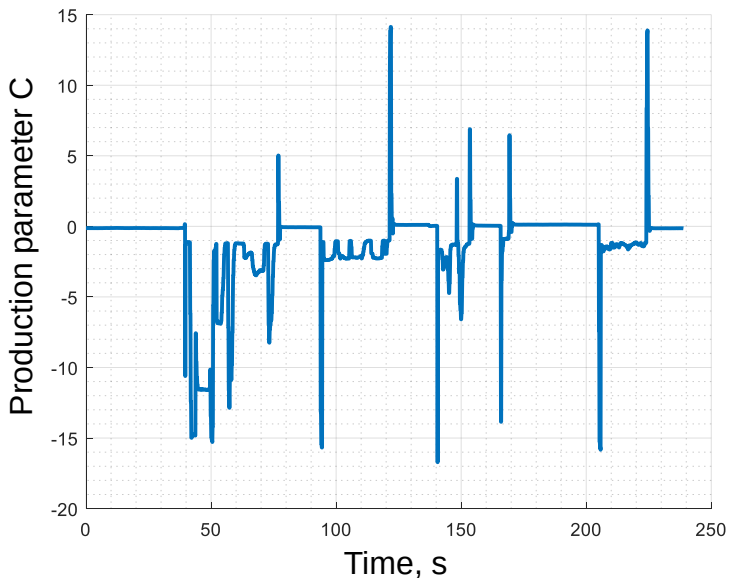
- Different parameters show very different and elaborate features

Challenges

- About 700 parameters are continuously monitored in every production cycle yielding 700 individual time-series of about 2500 samples each



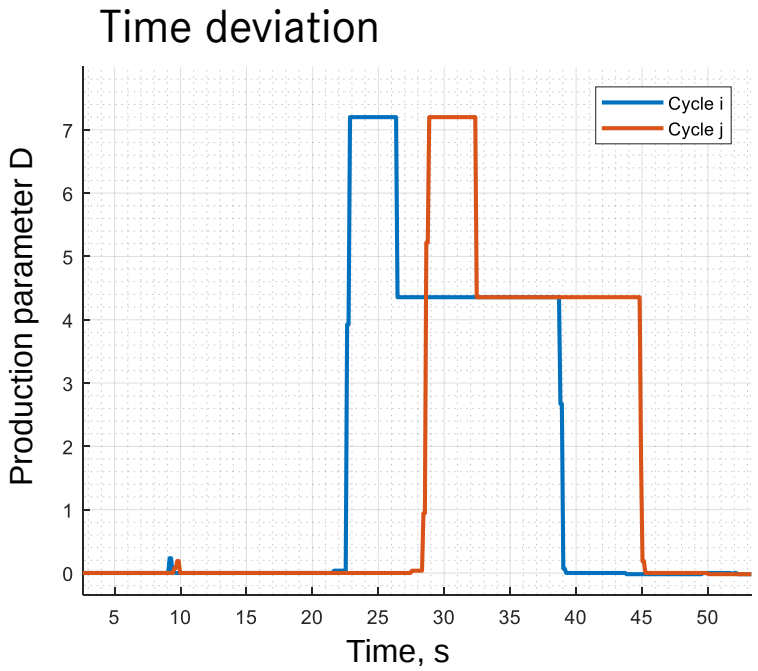




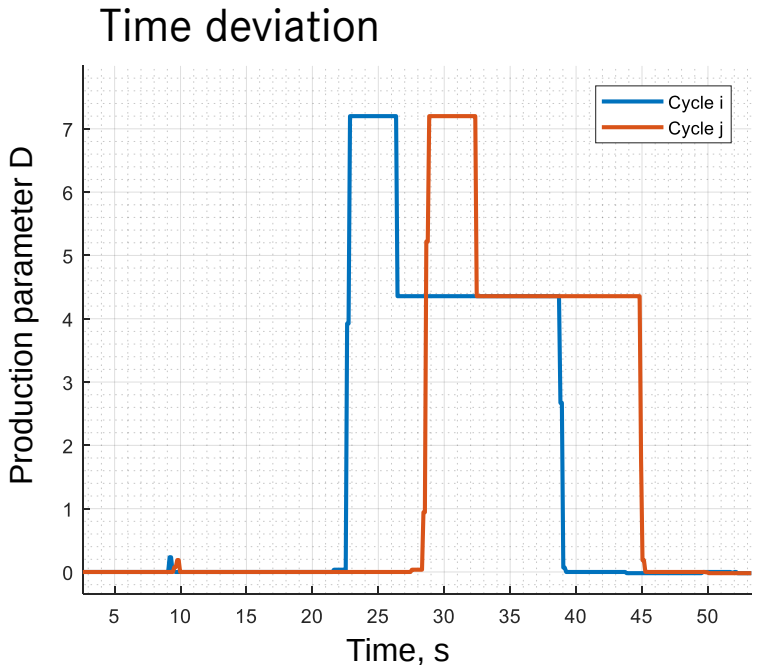
- Different parameters show very different and elaborate features

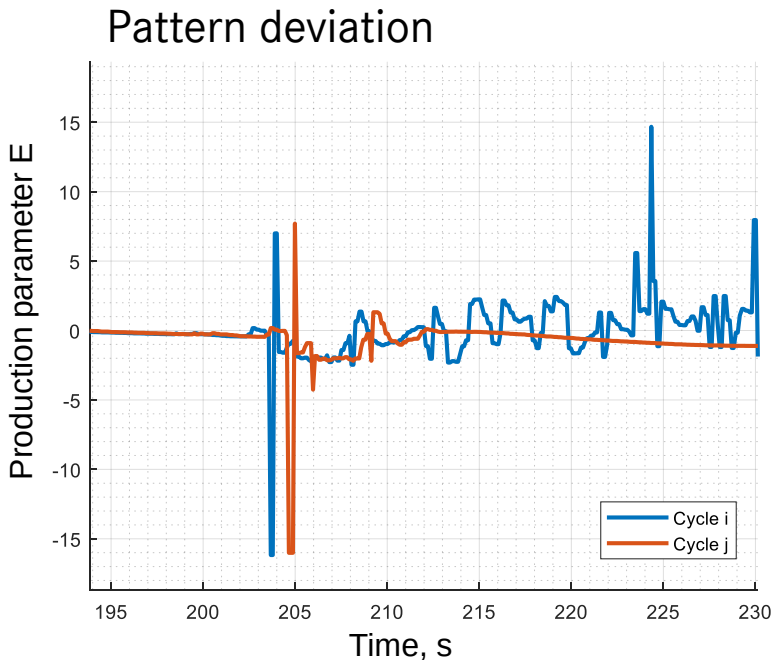
⇨ Task: Analyse these 700 time-series and find specific kinds of deviations

Requirements for algorithm



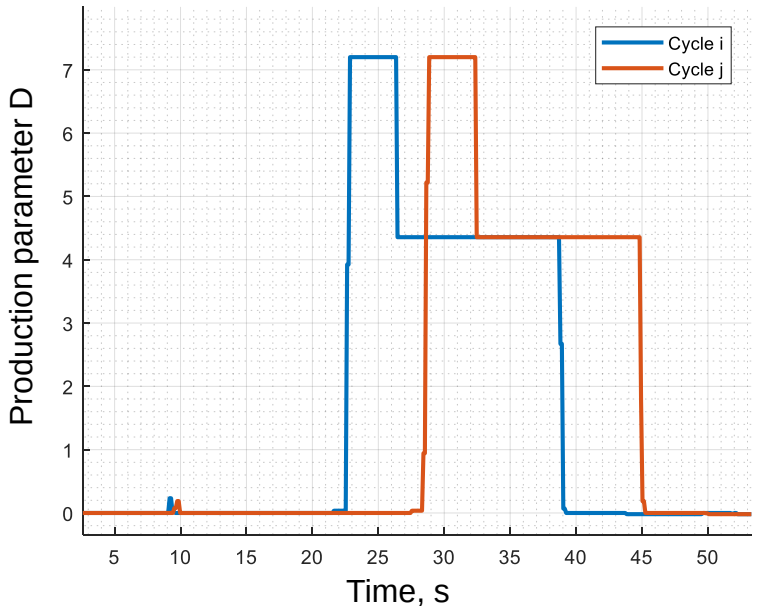
Requirements for algorithm



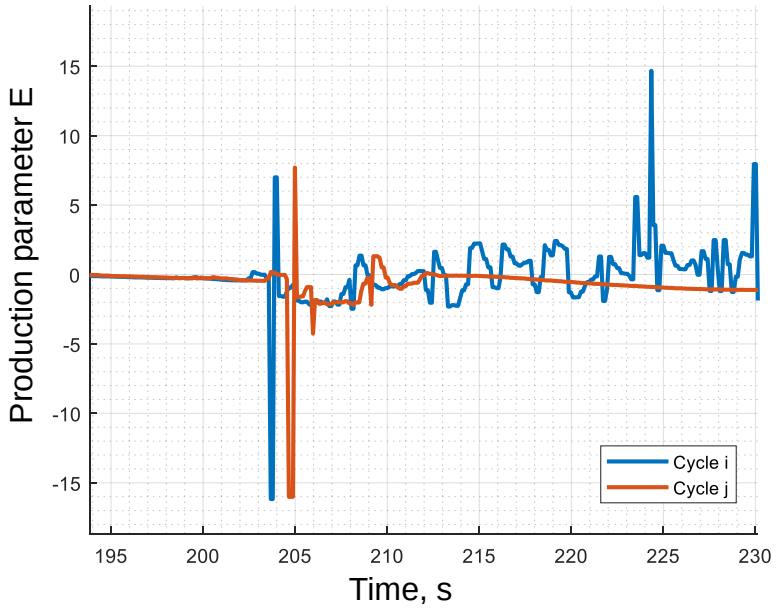


Requirements for algorithm

Time deviation might not be critical



Pattern deviation is critical



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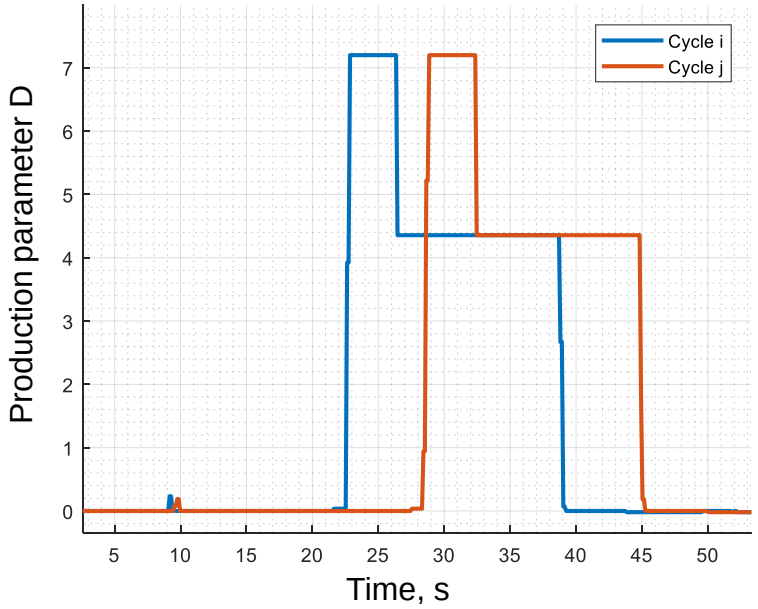
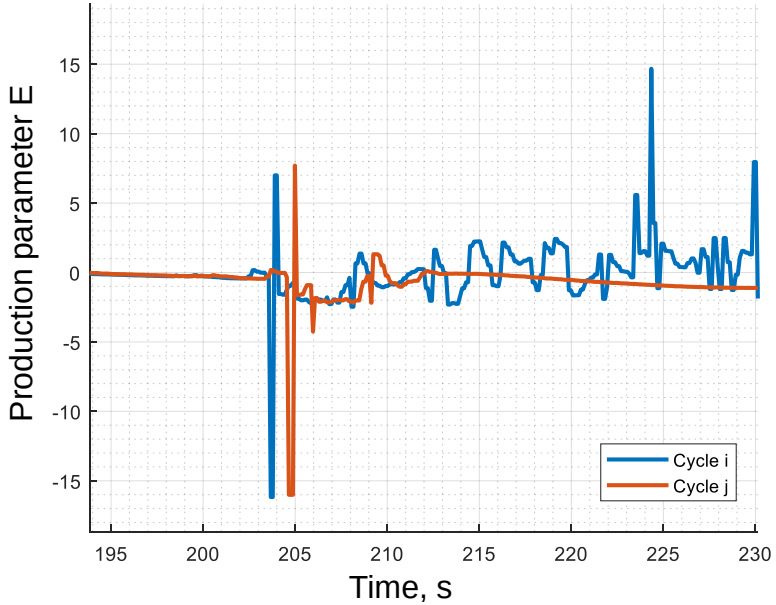


Pattern deviation is critical



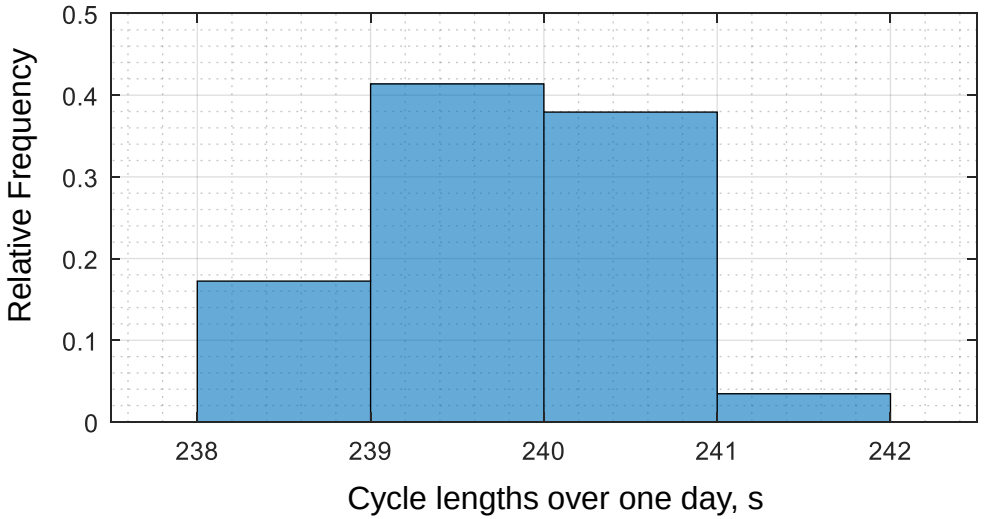
What the algorithm should do

- Time series analysis
- Find deviations from normal cycle and
- Distinguishing between time and pattern deviation

What is *normal*?

Delays in production cycles

- Length of time-series varies from cycle to cycle even for normal production



Delays in production cycles

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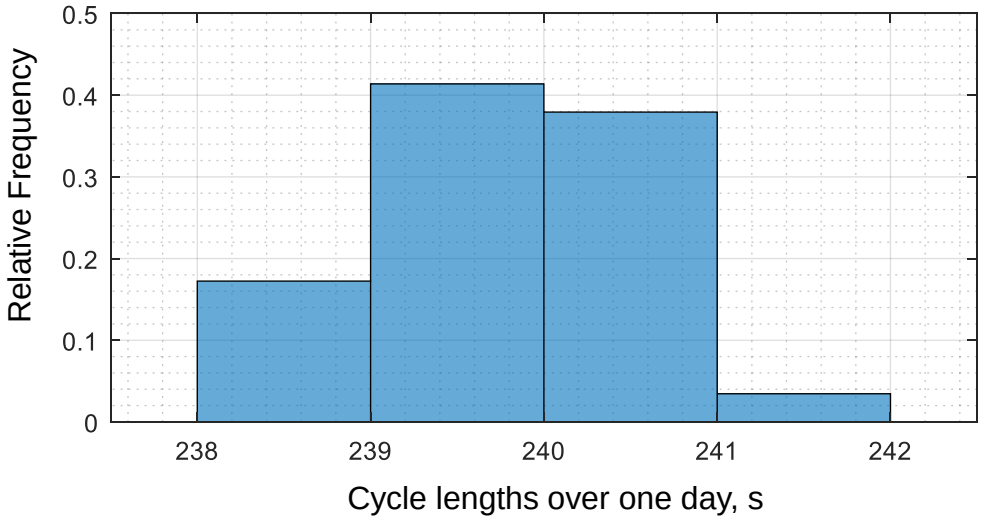

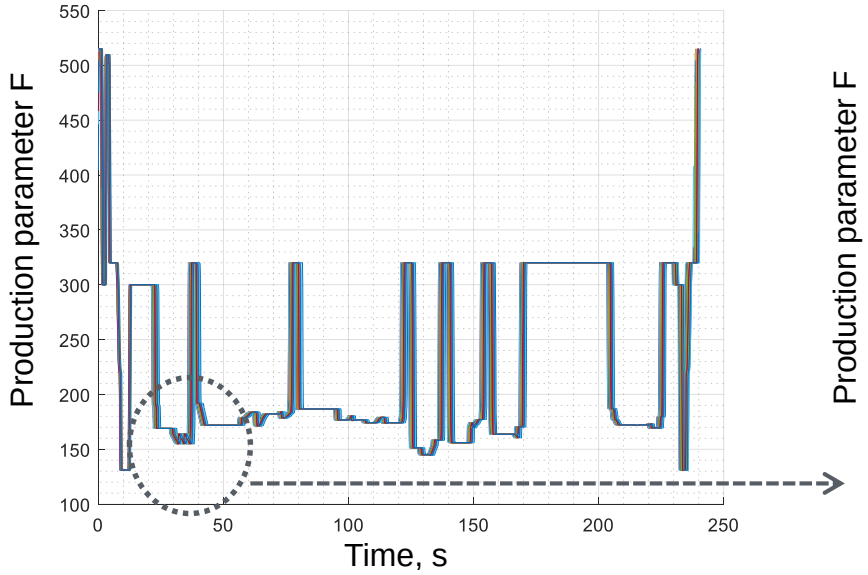

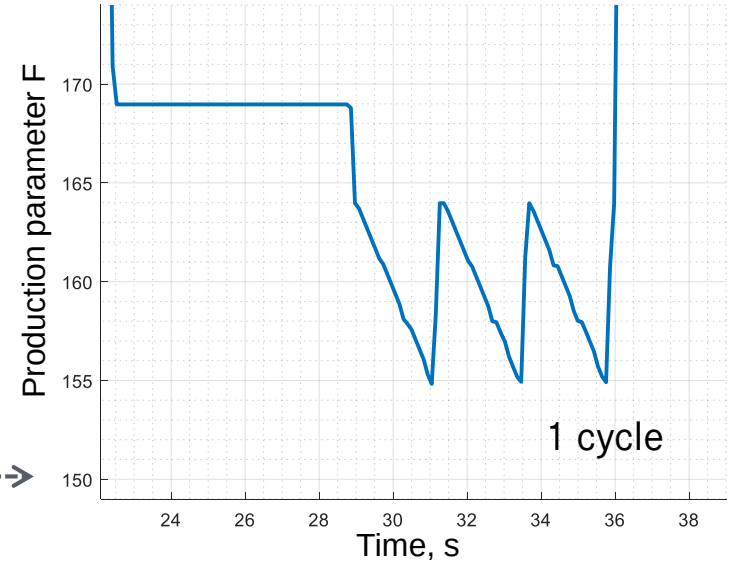

Delays in production cycles

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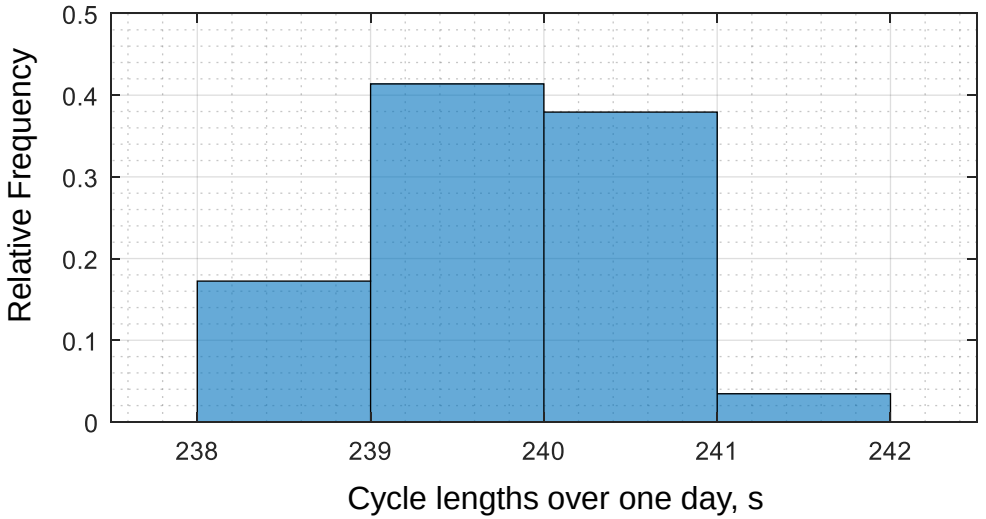

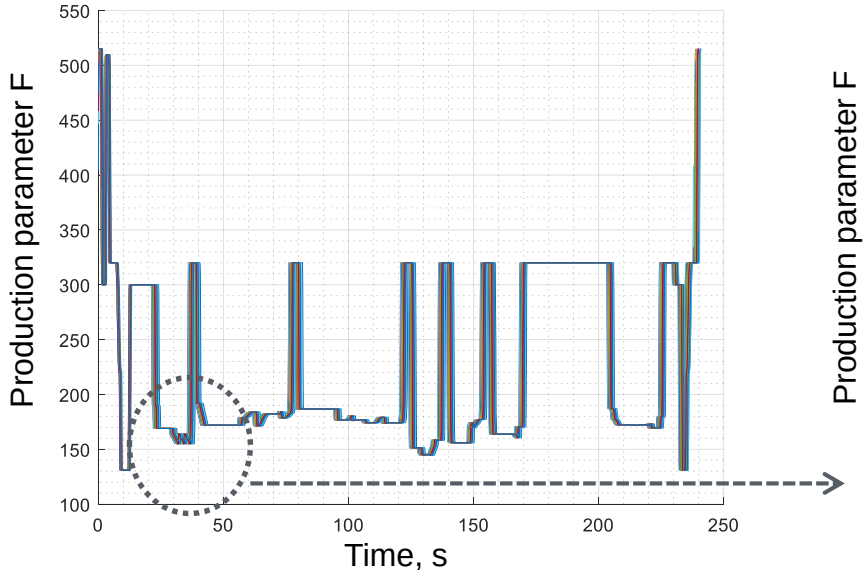

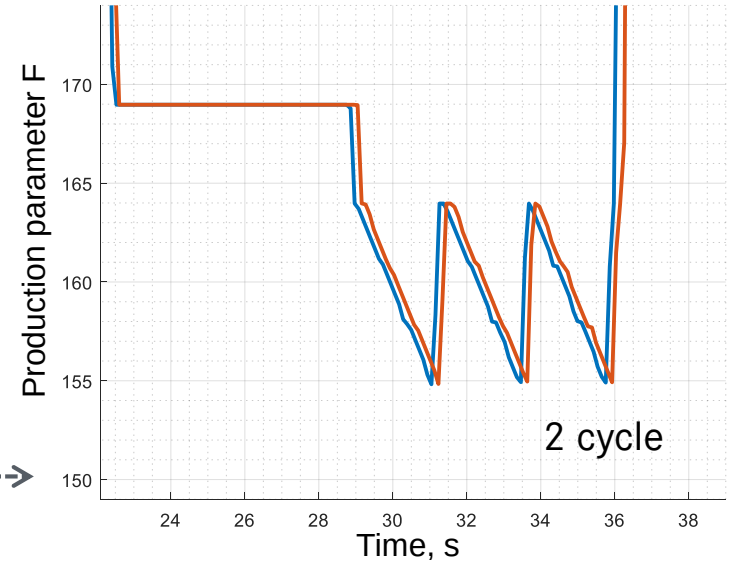

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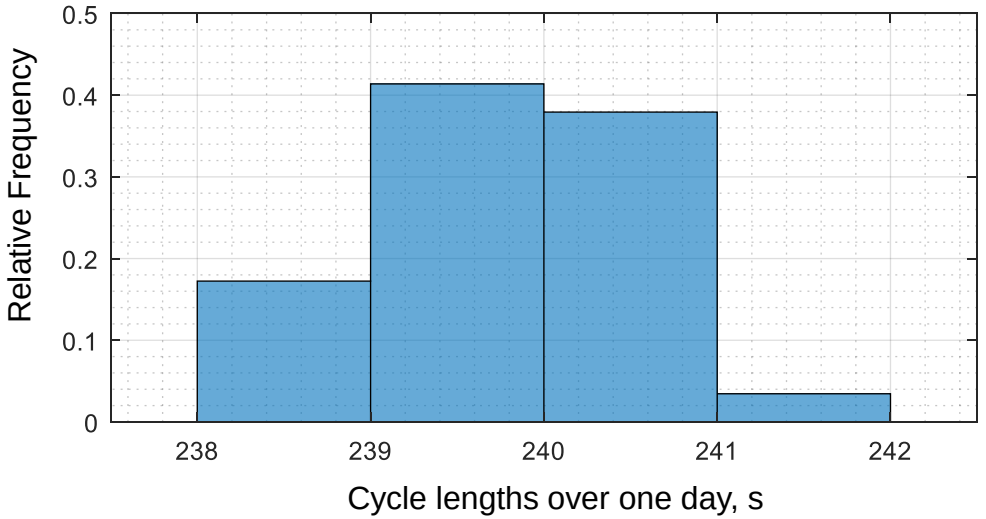

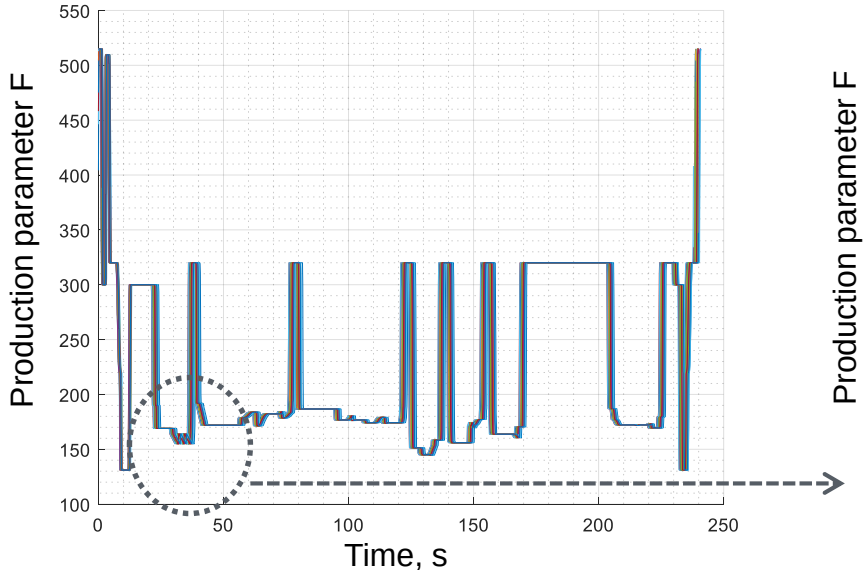

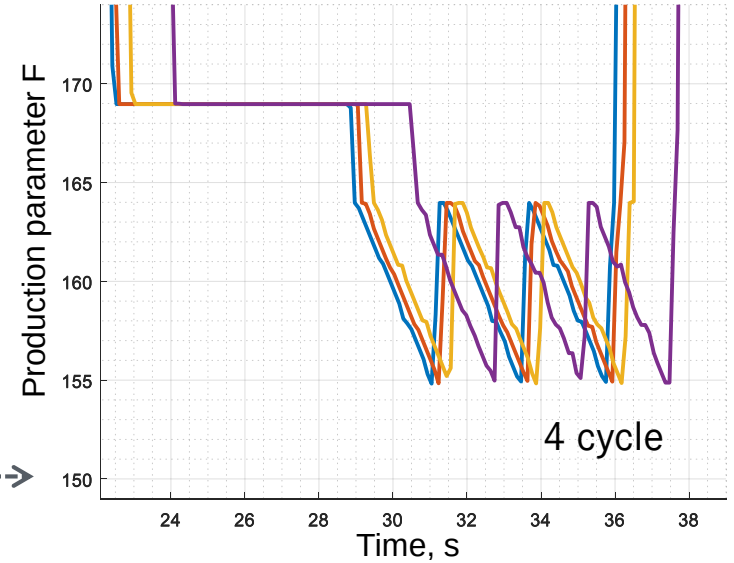

Delays in production cycles

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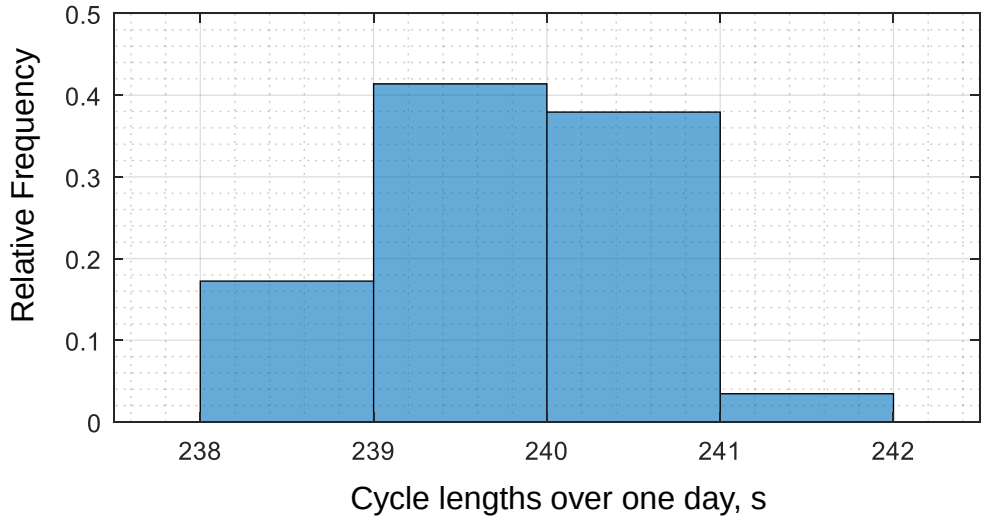
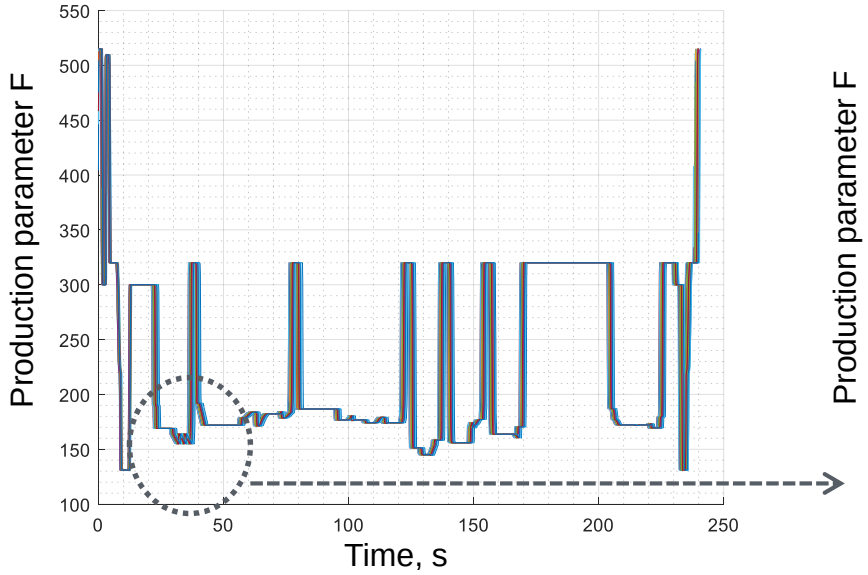
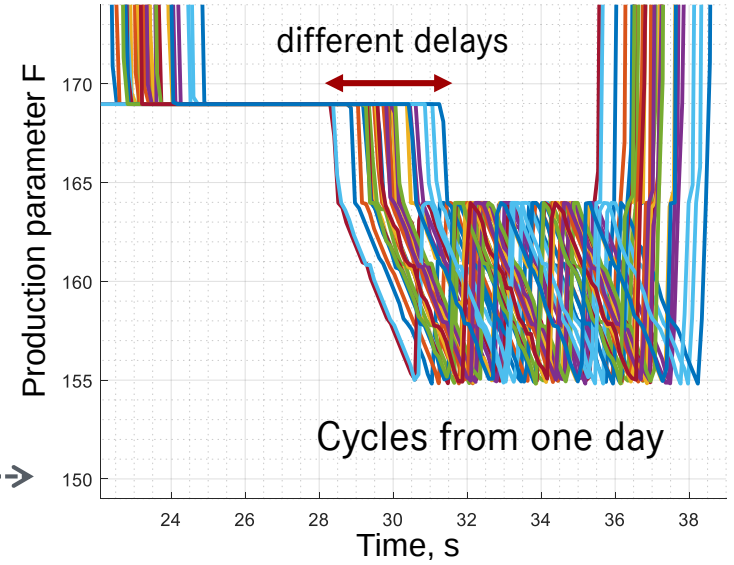


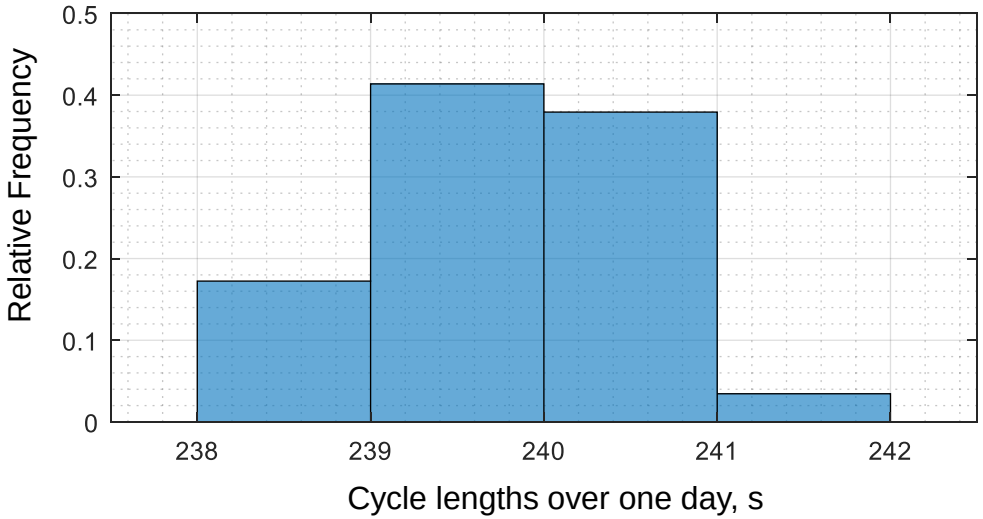


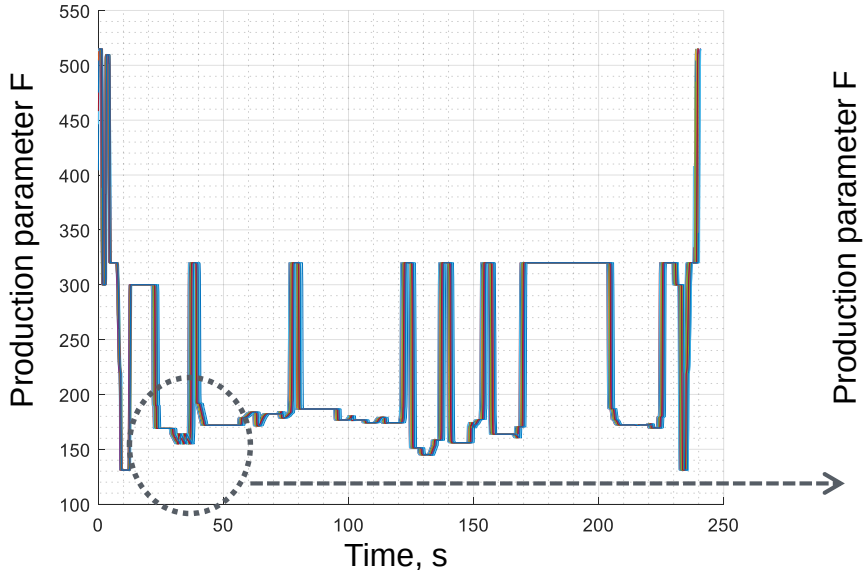


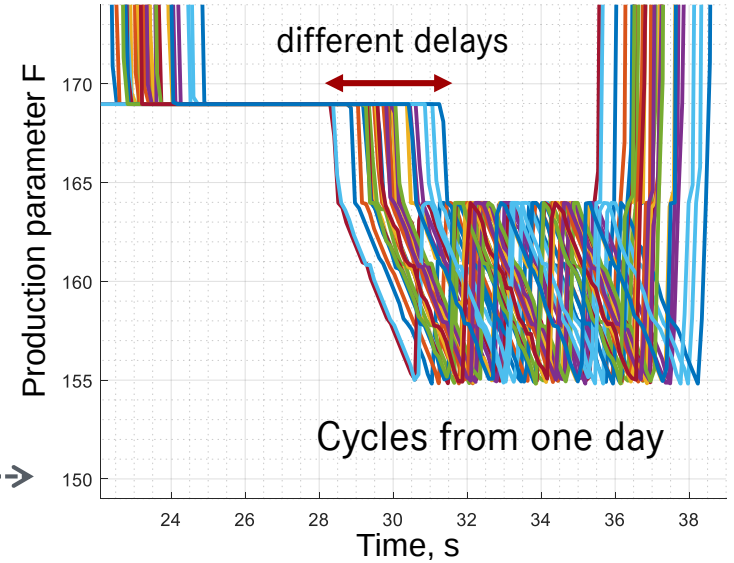
Delays in production cycles

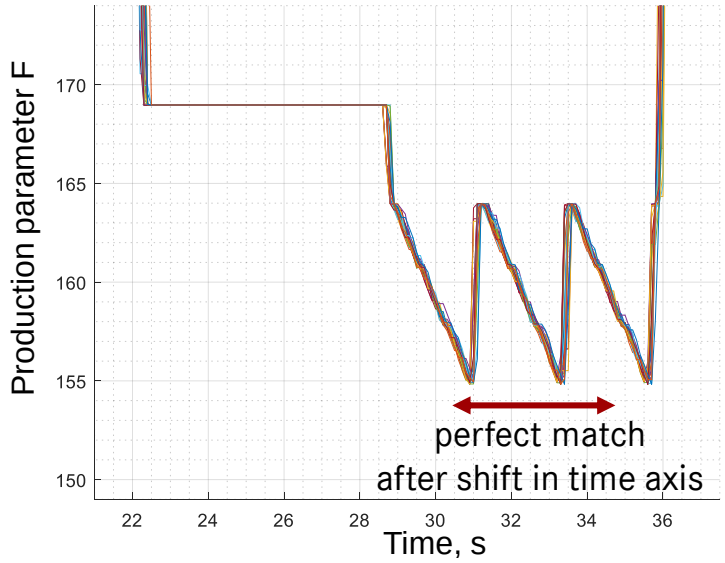
- Length of time-series varies from cycle to cycle even for normal production

⇨ Normal cycles can be matched to one another through shifting in time axis!

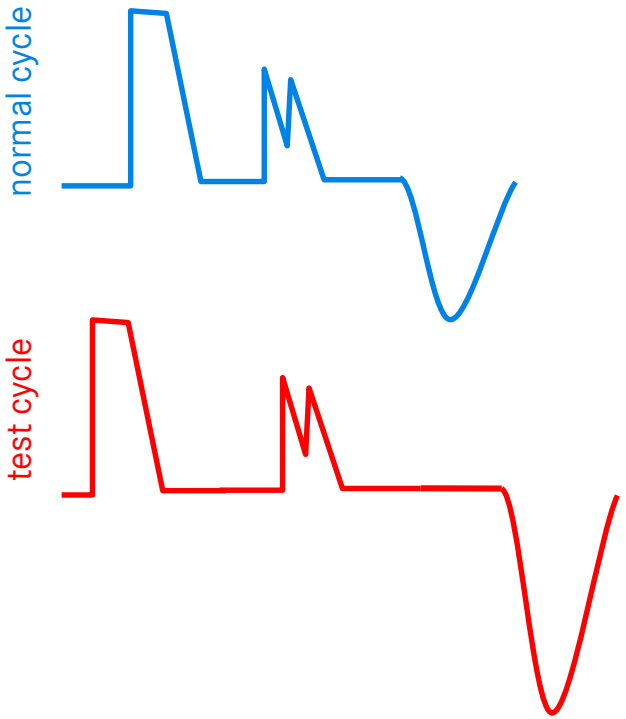








Algorithm principle



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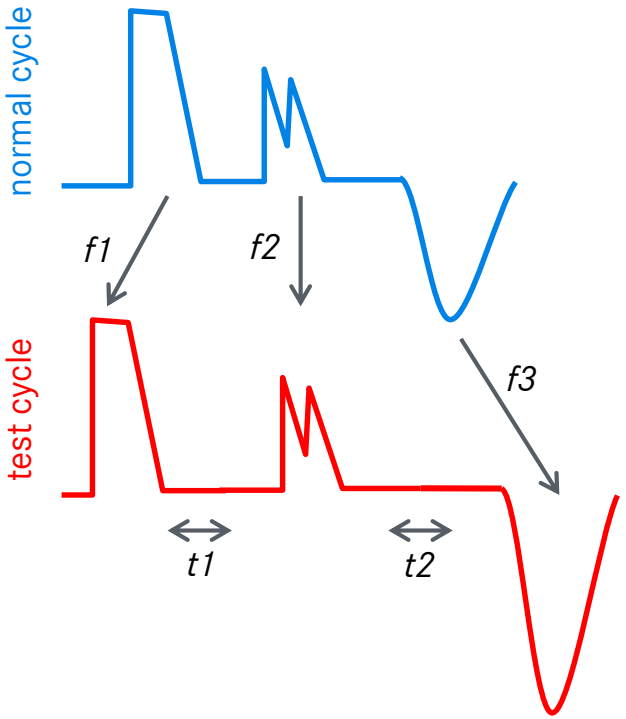
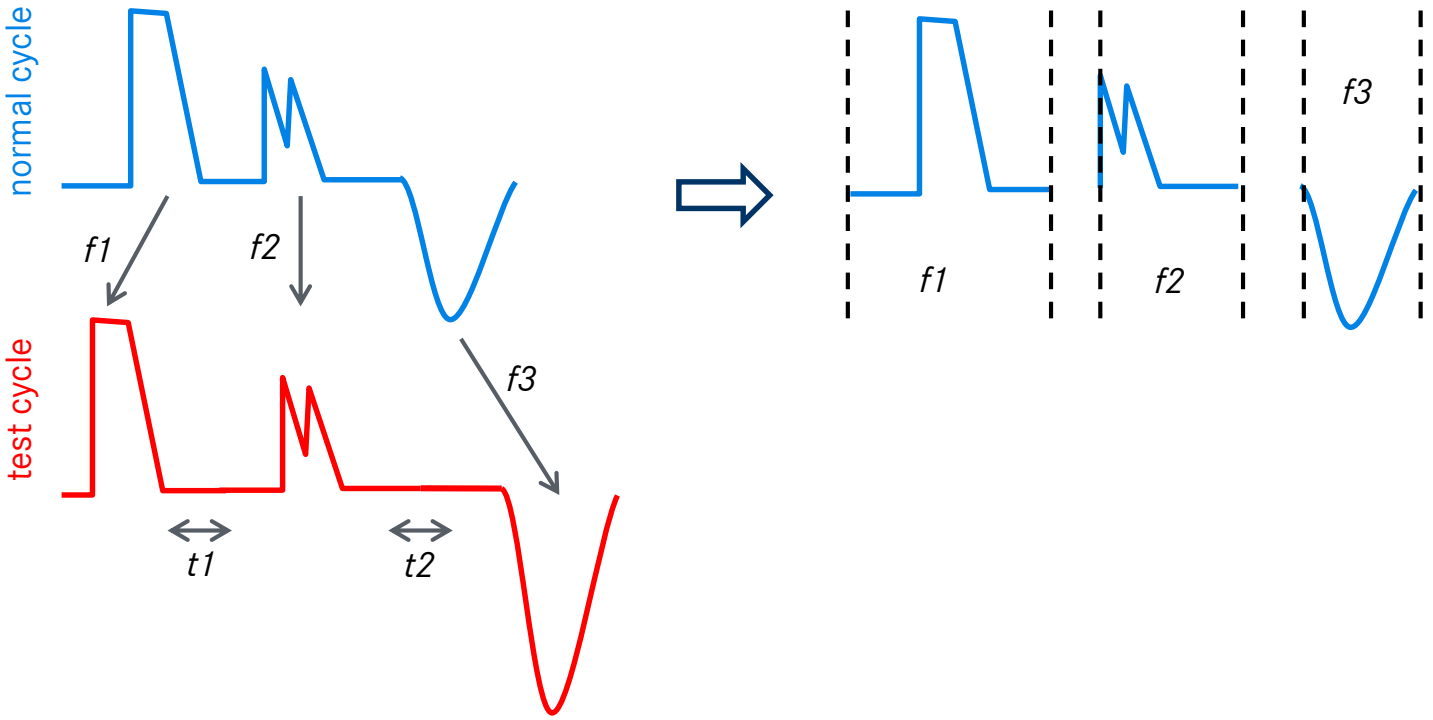


- Cycle can be described as sequence of features f1, f2, f3
- Each cycle can show some delays in time t1, t2

Algorithm principle



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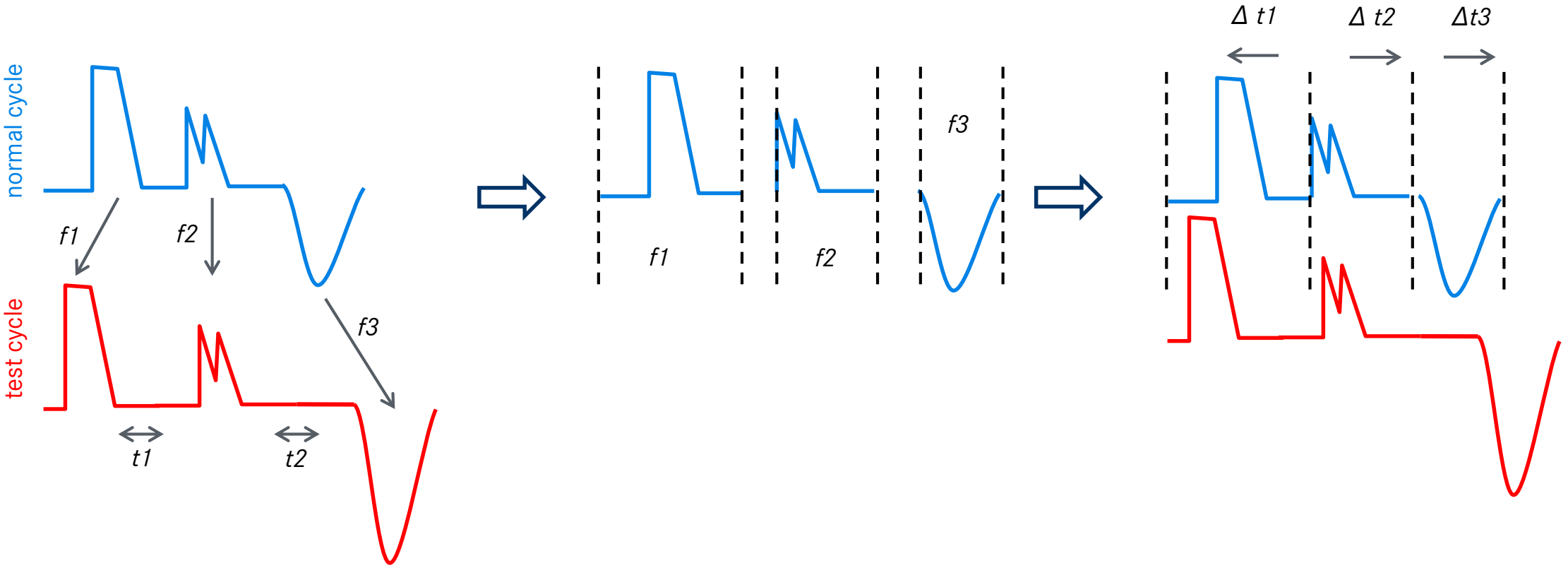
- Automatic feature detection *f1, f2, f3*

Algorithm principle

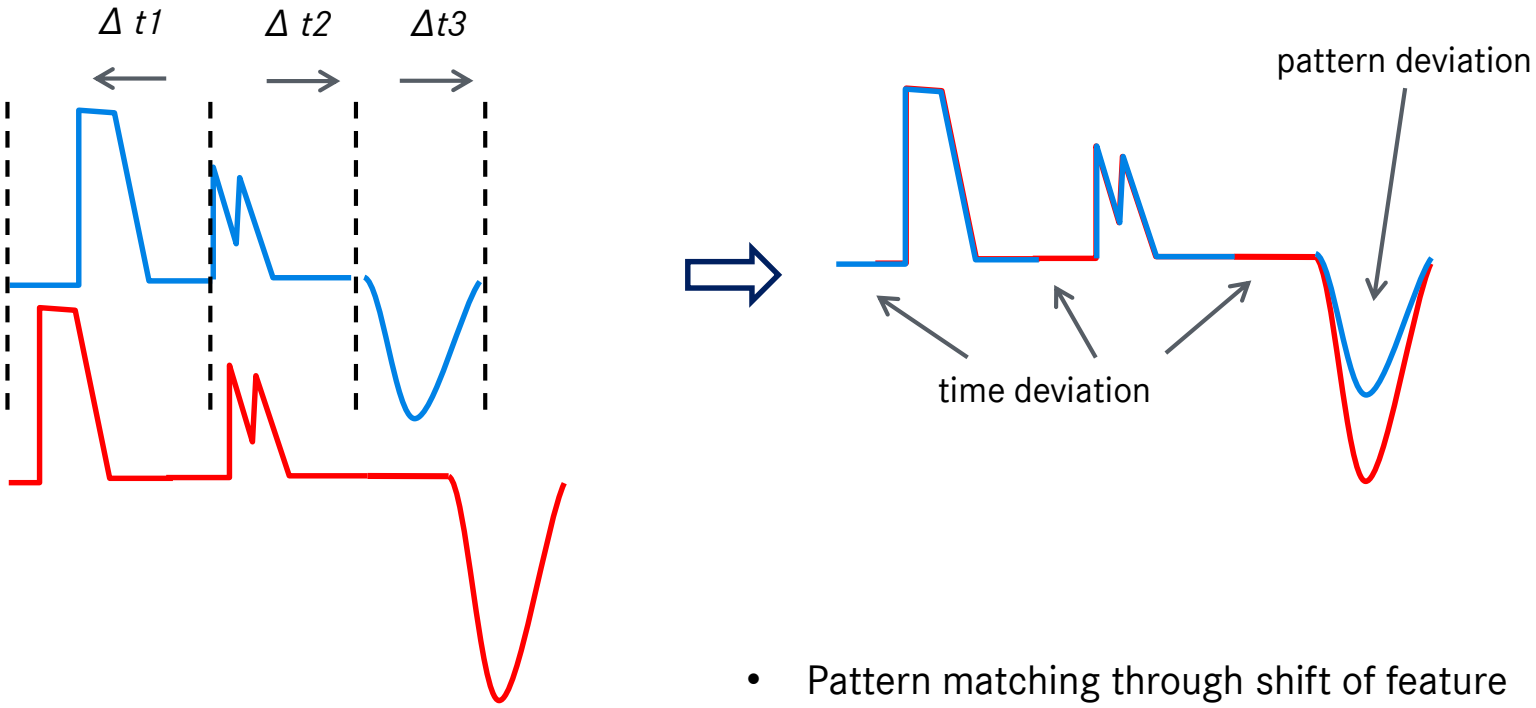


- Cycle can be described as sequence of features f1, f2, f3
- Each cycle can show some delays in time t1, t2

- Automatic feature detection *f1, f2, f3*

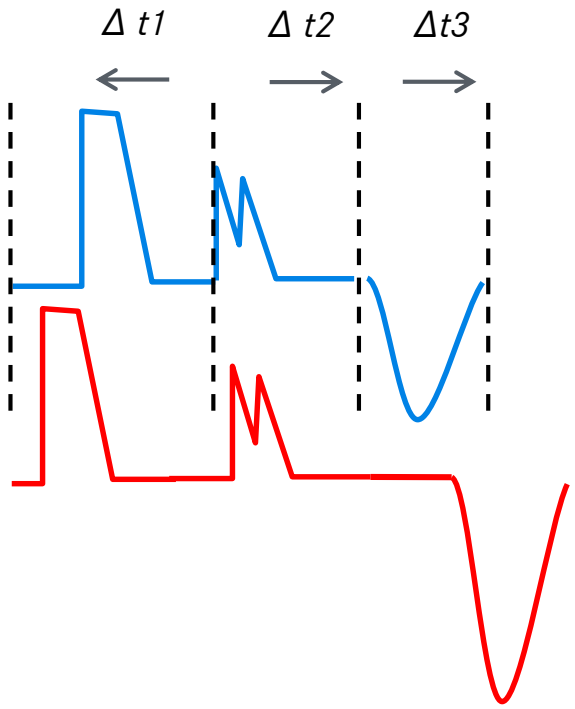
- Pattern matching through shift of feature along time axis (*Δt2, Δt2, Δt3*): least square fit (t_{shift} to minimize the Sum of Residual Squares of two signals)

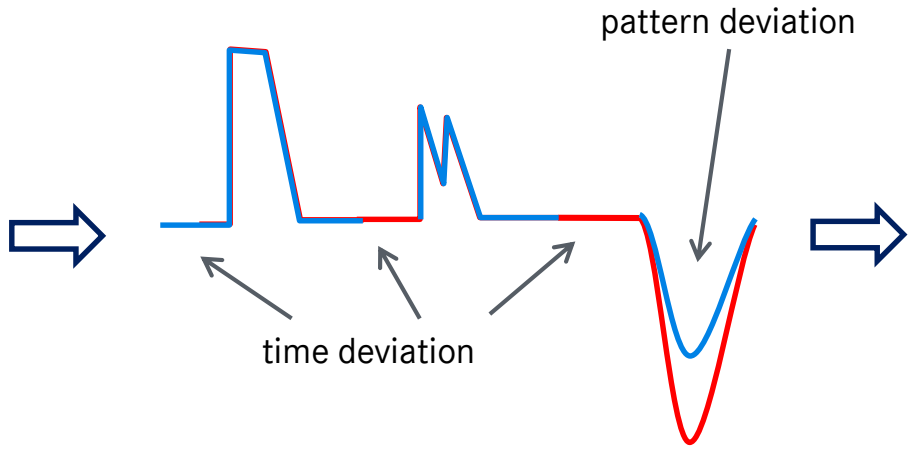
Algorithm principle



- Pattern matching through shift of feature along time axis (*Δt2, Δt2, Δt3*): minimization of SRS

Algorithm principle





f1	*f2*	*f3*	
Δt1	*Δt2*	*Δt3*	Time deviation
No	No	Yes	Pattern deviation

- Pattern matching through shift of feature along time axis (*Δt1, Δt2, Δt3*): minimization of SRS

- Decription of a cycle as feature sequence
- For each feature time and pattern deviation can be calculated

- Time and pattern deviation for each feature are used as characteristic numbers for test cycle

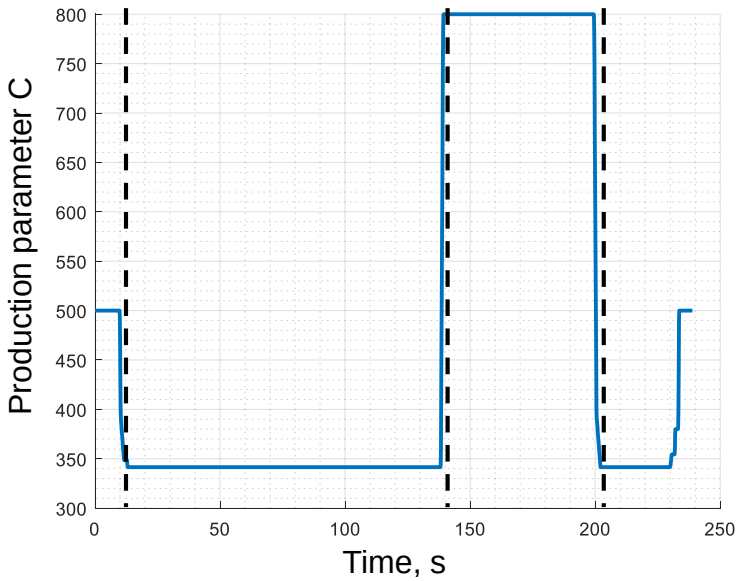
⇨ Data reduction!

Automatic feature detection

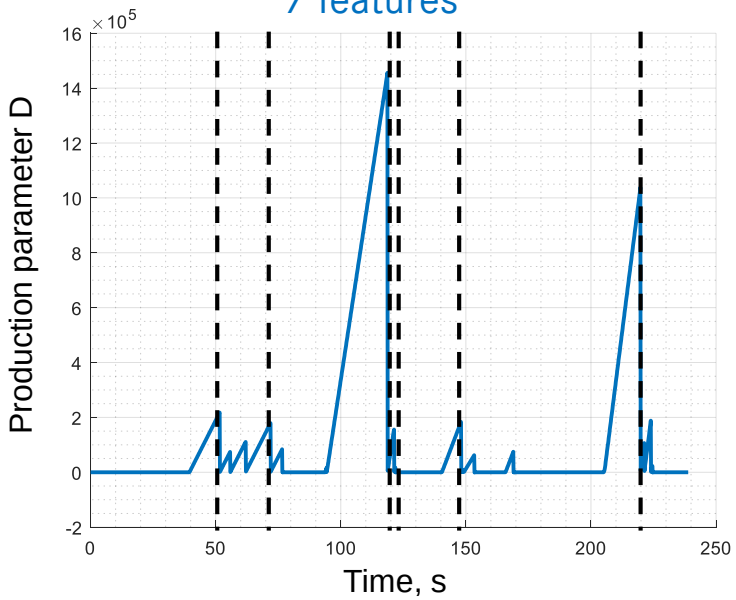
Time series is split

- After a local extremum (maximum or minimum) or on a plateau
- After a given relative change

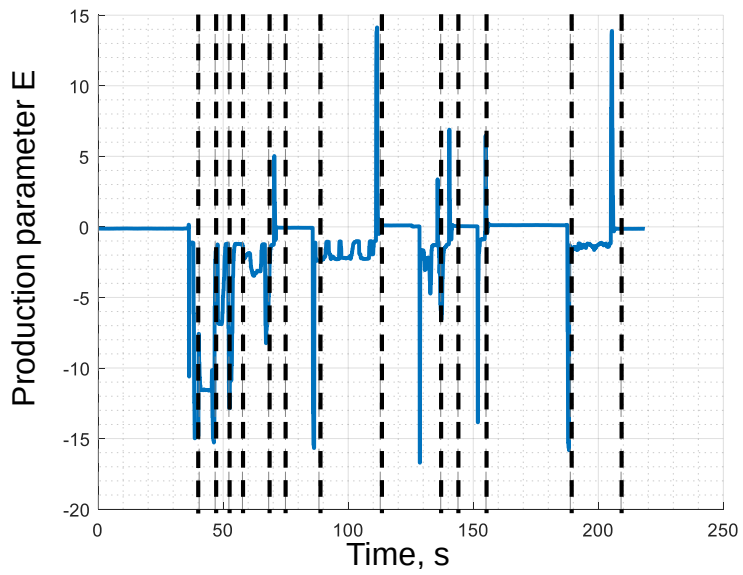
4 features



7 features



14 features



⇨ Data reduction of time series from 2500 datapoints to sequence of max. 60 features (typically 10)!

Algorithm implementation: machine learning approach in MATLAB

Training

Reference cycles ->

- Build „reference signal“ for each feature
- Limits for time and pattern deviation

Testing

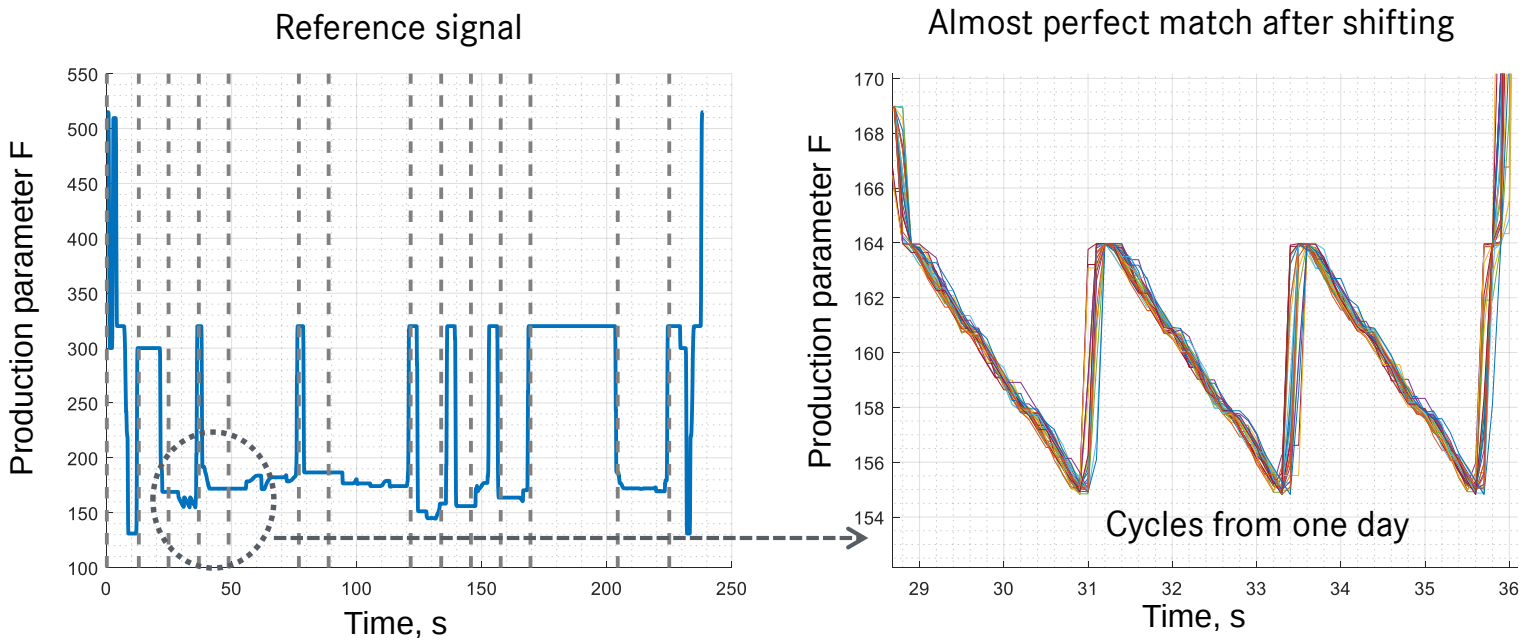
Test cycles ->

- Comparison of each feature in reference signal
- Is time and pattern deviation within the limits?

Create „reference signal“ for each produciton parameter

Training

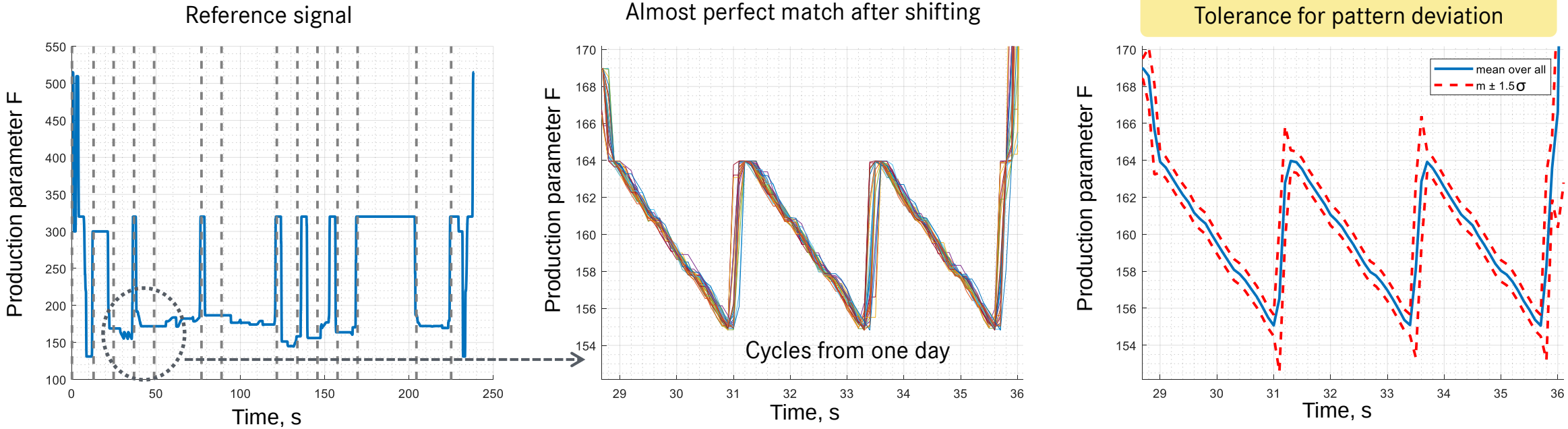
1. For all training cycles - matching to shortest cycle
2. Create „reference signal“ – mean over all matched reference cycles



Create „reference signal“ for each produciton parameter

Training

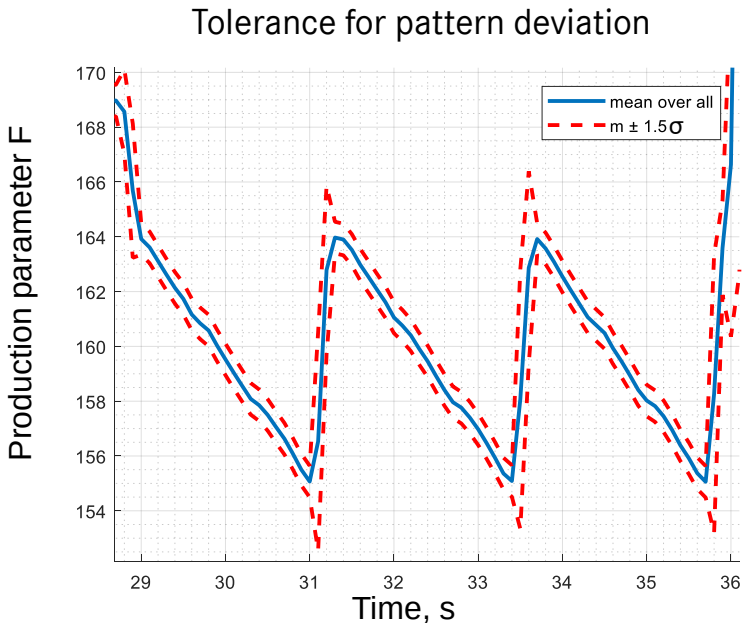
1. For all training cycles - matching to shortest cycle
2. Create „reference signal“ – mean over all matched reference cycles
3. Possible pattern deviation - standard deviation over all matched reference cycles

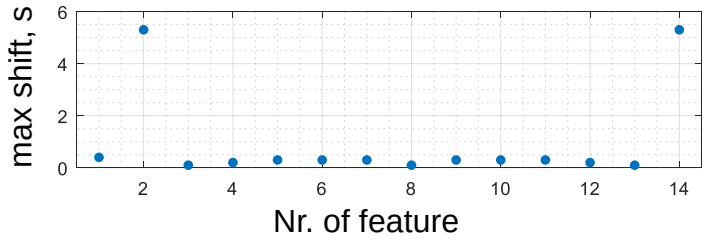


Create „reference signal“ for each produciton parameter

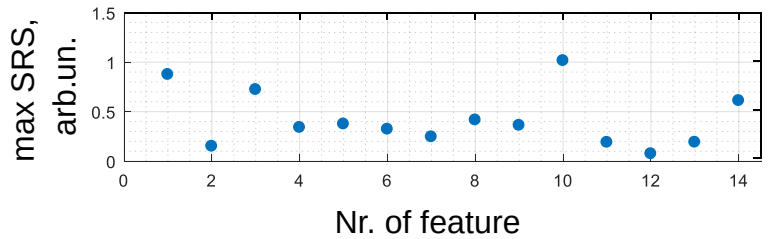
Training

1. Create „reference signal“ – mean over all matched reference cycles
2. Possible pattern deviation - standard deviation over all matched reference cycles, limits for SRS
3. Possible time deviation – maximal absolute shift from matched reference cycles





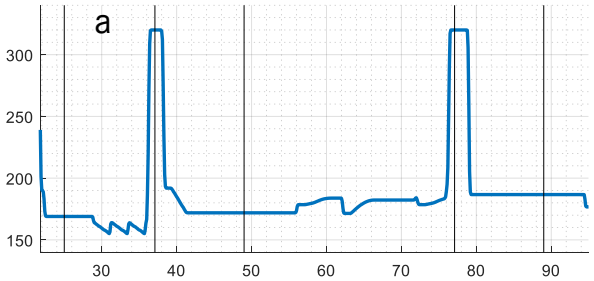
Possible time deviation



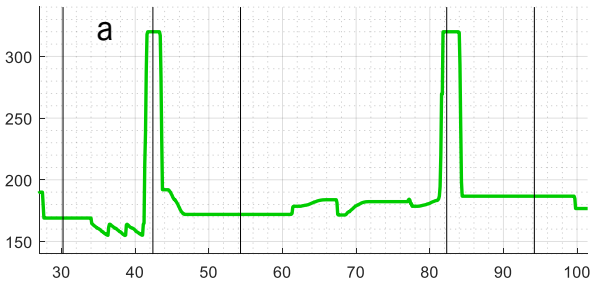
Possible pattern deviation

Testing: time and pattern deviation evaluation

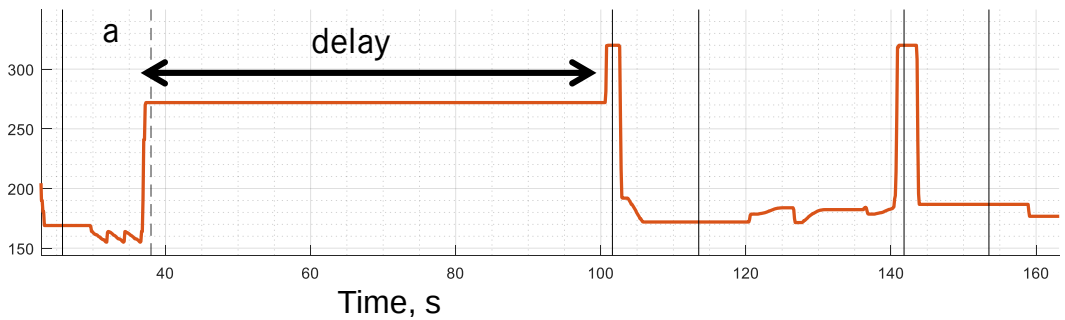
reference signal



normal cycle



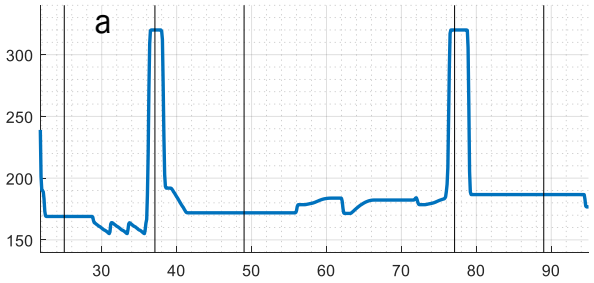
error cycle



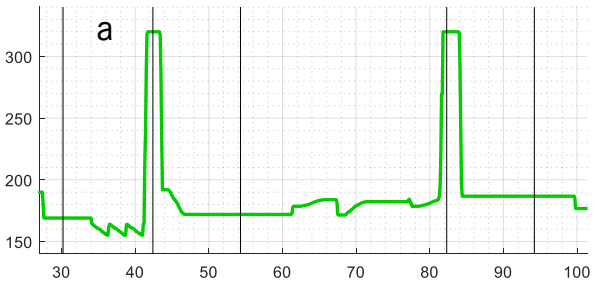
Production parameter F

Testing: time and pattern deviation evaluation

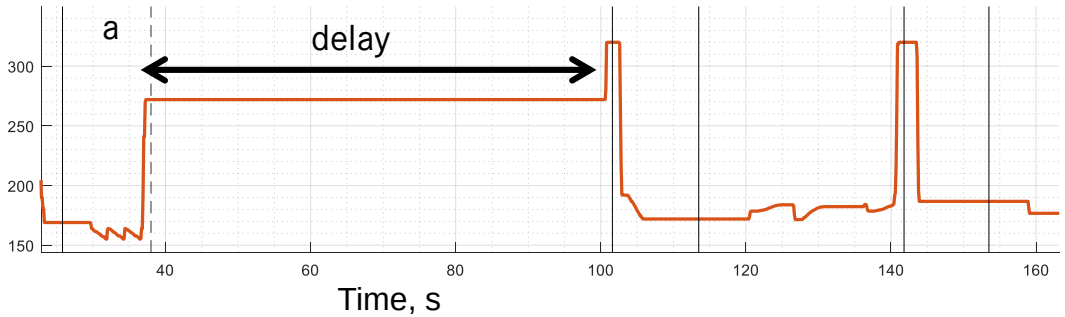
reference signal



normal cycle



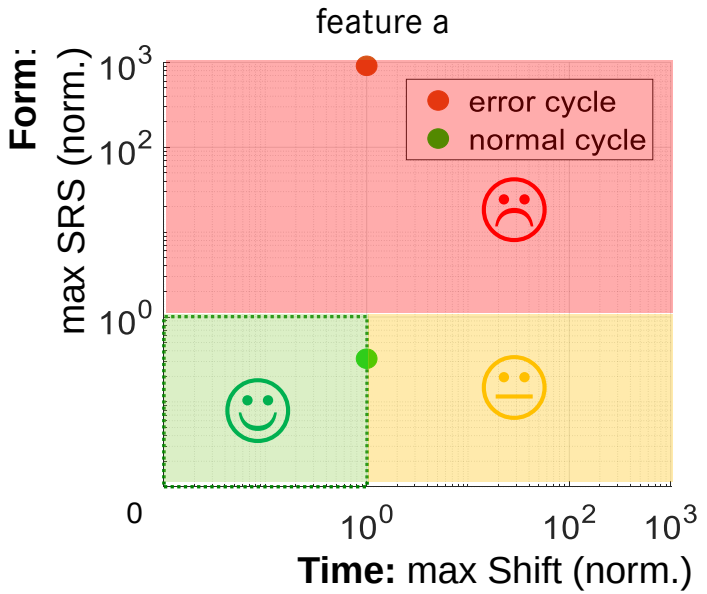
error cycle



Production parameter F

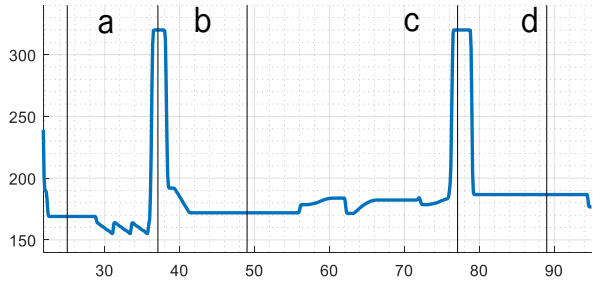
Is time and pattern deviation for this feature within the limits?

- Tolerance window (Δt, *SRS*)
- Easy to spot a critical deviation

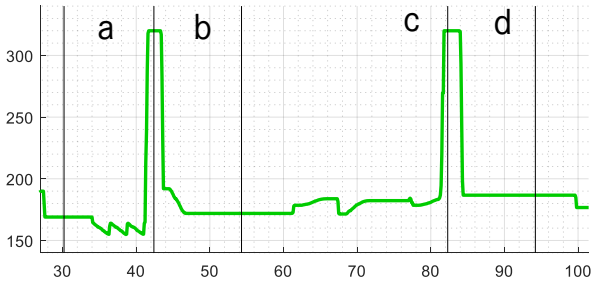


Testing: time and pattern deviation evaluation

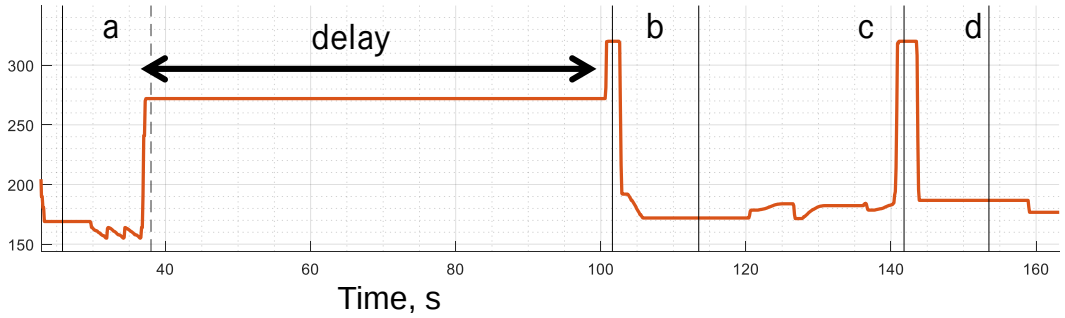
reference signal



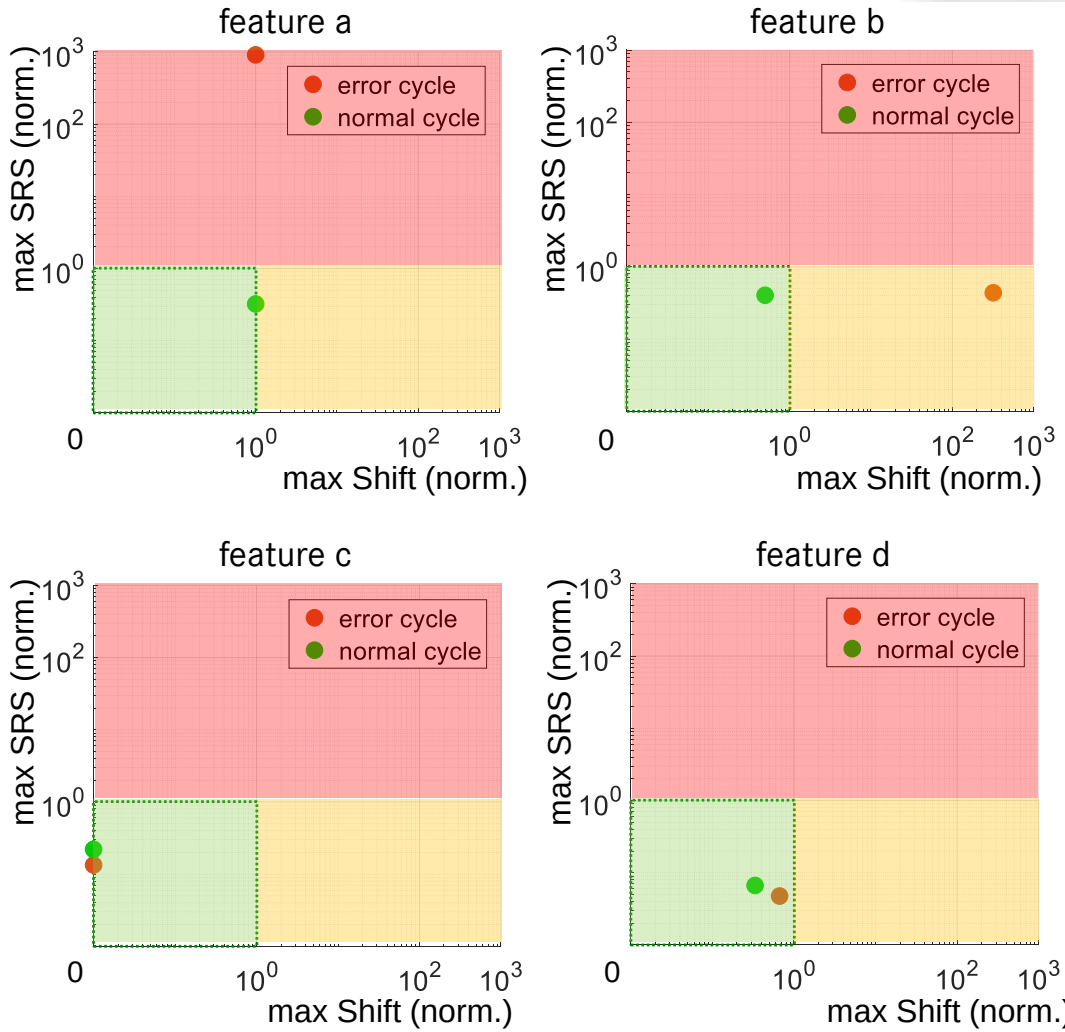
normal cycle



error cycle



Production parameter F



Algorithm: Summary

1. Quantitative and qualitative description of production failure
2. Independent of signal form -> universally applicable to other applications or machines
3. Signal description with characteristic numbers, which are easy to interpret
4. Data reduction with a factor **250** without significant loss of information!
5. Easy control of production: recognition of critical errors and non-critical delays online

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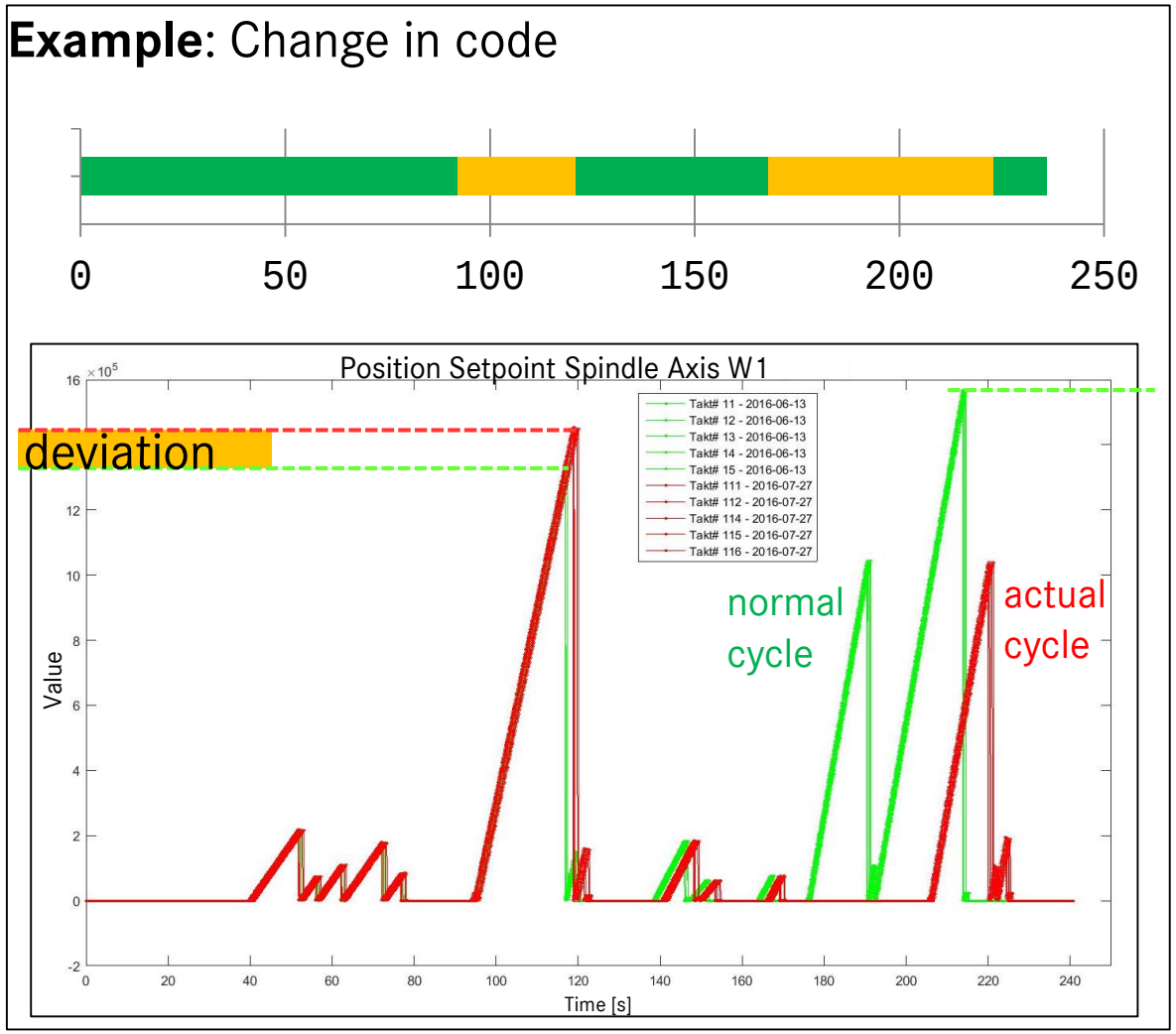
Example of the added value



Results:

- Transparency of the process
- Deviation for each Signal
- Reason of Cycletime increase found

➔ Time and Pattern deviation are recognized

Summary

Algorithm using pattern matching for time series developed and implemented for production data

Why MATLAB?

- easy algorithm implementation
- existing solution for data import
- very good support and broad use in universities

MathWorks products used:

- Signal Processing Toolbox
- Statistics and Machine Learning Toolbox

Outlook:

- Parallel Computing Toolbox for performance improvement

Prototyp intelligent Level-Learning (iLL) has a new function for anomaly detection

- Troubleshooting in case of failure (maintenance), Parts Planning, Influences on the quality
  ➔ Optimization of repair time, spreaders amount, …

Thank you for your attention!

Mercedes-Benz

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