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Fraunhofer-Institut für Verfahrens-
technik und Verpackung IVV

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CYBER PHYSICAL CLEANING SYSTEMS: A THREE LEVEL APPROACH

Cyber Physical Systems

Cyber Physical Cleaning Systems

- Cyber Physical System: physical systems with embedded sensors, processors and actuators that can be controlled or monitored by computers (Xu and Duan, 2019; Lee, 2015; Yang Lui et.al. 2017)
  - may improve adaptability and resiliency of physical systems
  - opportunity for adaptive and efficient cleaning processes

- it is proposed that Cyber Physical Cleaning Systems are characterized by
  - inline monitoring of the soiling on relevant product contact surfaces,
  - adaptive cleaning devices and
  - adjustment of process parameters.

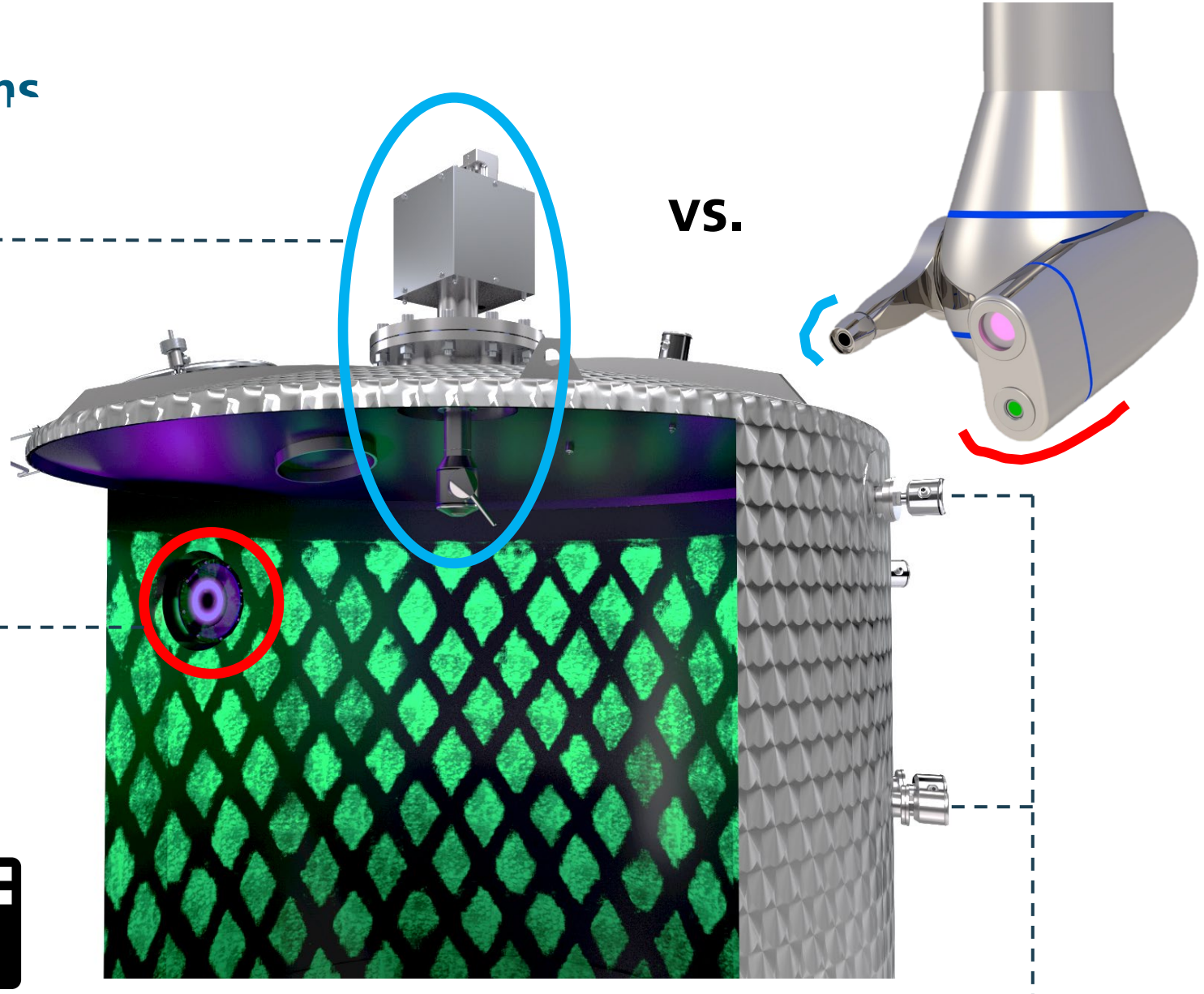
Cyber Physical Cleaning Systems

Vessel Cleaning

Adaptive cleaning device: Motor-driven cleaning device, two axes, independently rotating from each other

Camera / Optical cleaning sensor / other sensors

Process control



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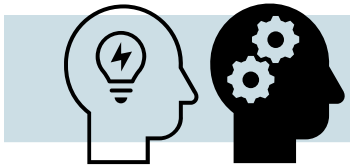
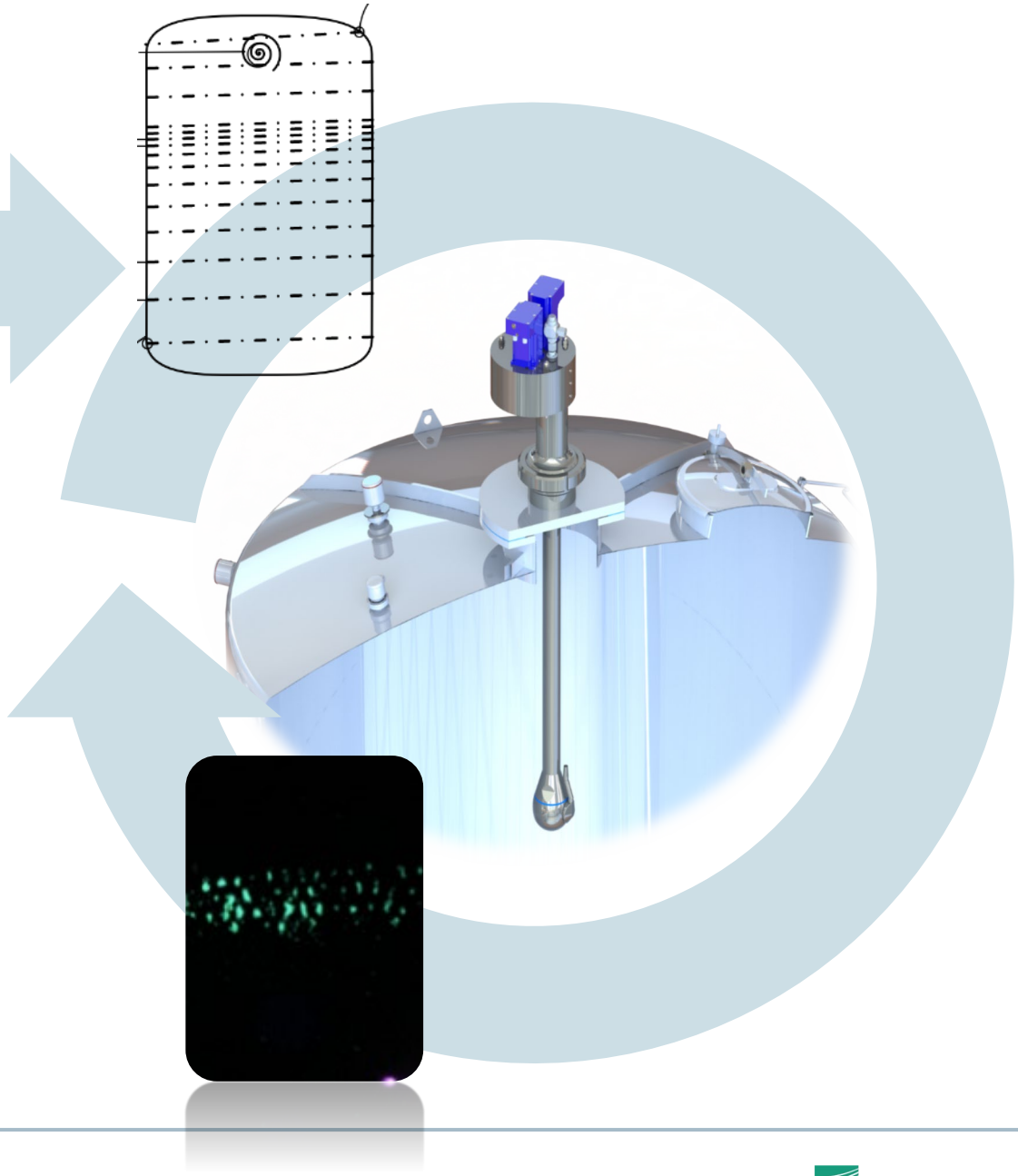
Level 1

A semi-empirical, adaptive approach



Principle Workflow:

1. Input: Subject matter expert knowledge, vessel geometry, location of hard to clean areas, type of food product, cleaning models, simulation results,…,
2. Preoptimized cleaning procedure with adapted cleaning path and strategy for adaptive cleaning device based on fixed rule
3. Cleaning
4. Verifying cleaning result, maybe back to 3



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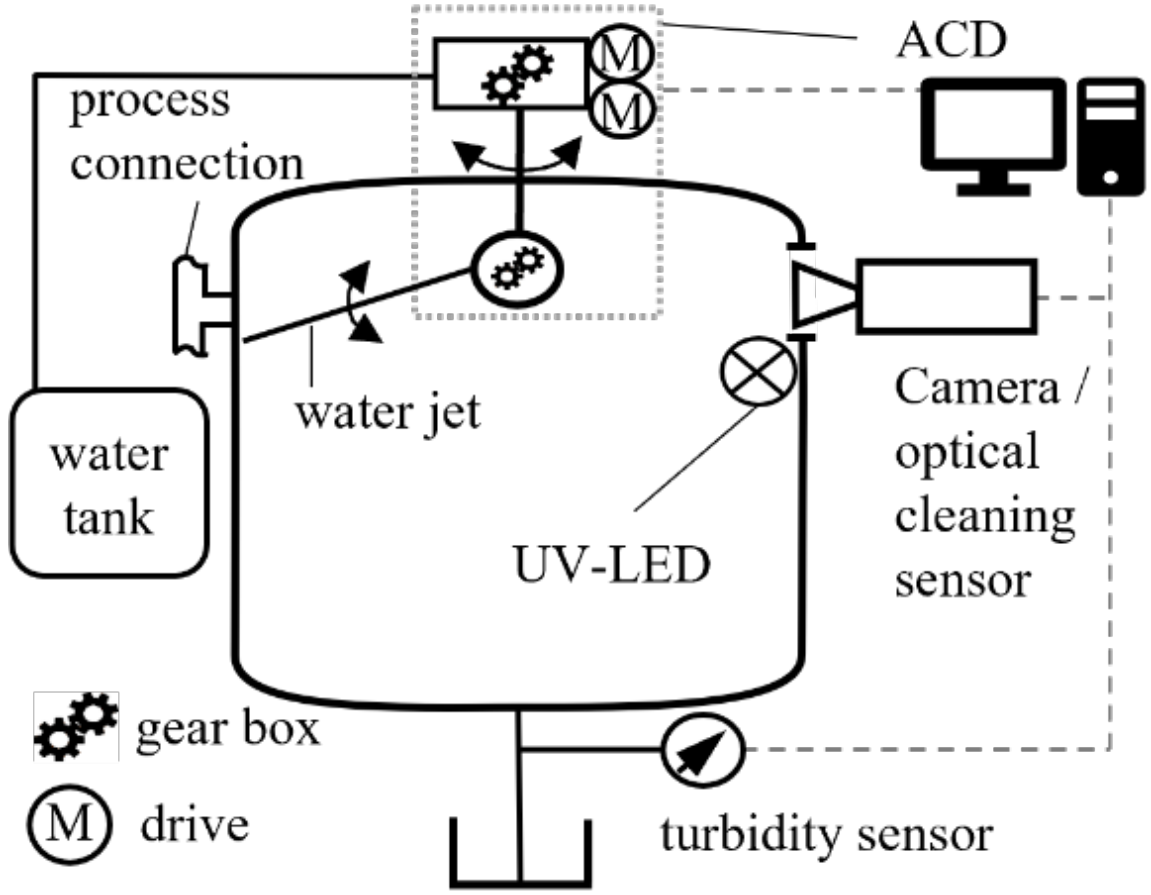
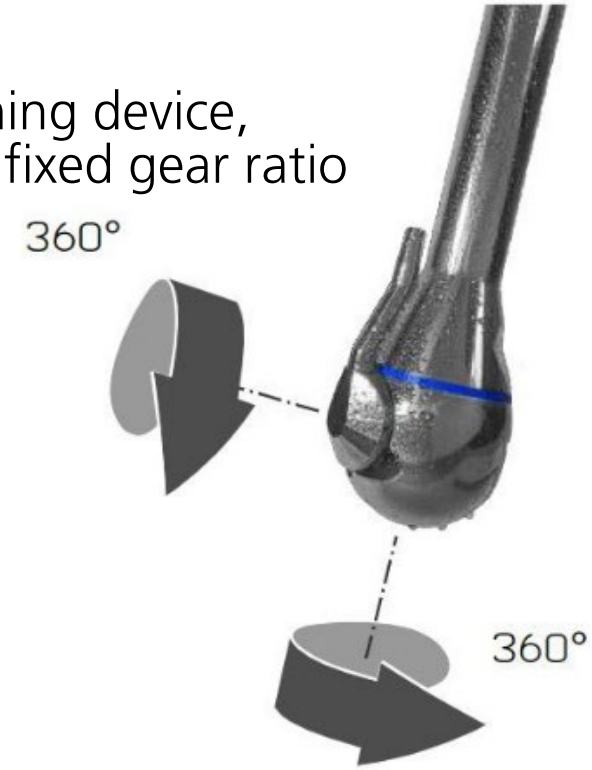
Level 1

Vessel cleaning tests: Comparision of standard & adapted cleaning pattern



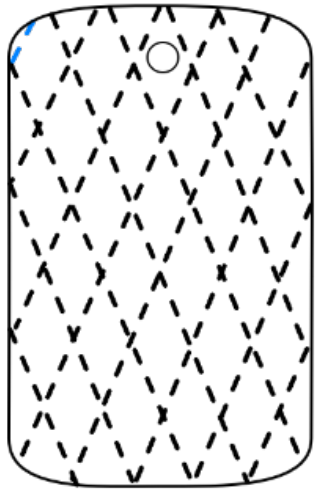
Adaptive cleaning device,
jet cleaner, no fixed gear ratio

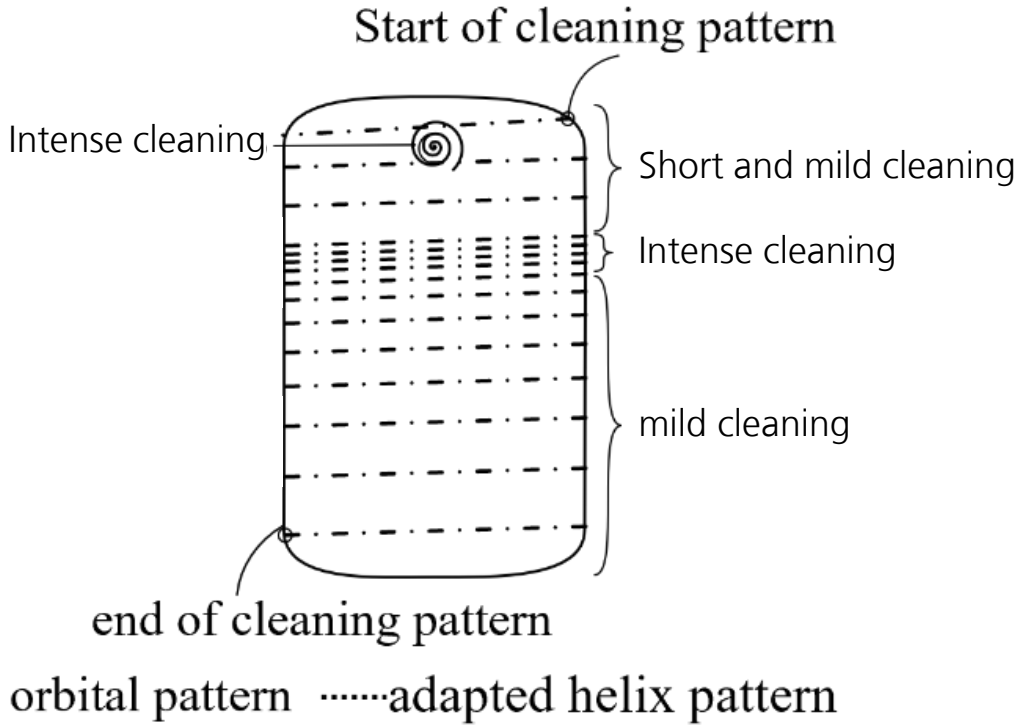


Soiling:	Vanilla pudding
Cleanng fluid:	Deionized water
Operating pressure:	3 bar (≈11,5L/min)
Vessel size:	10.000 l

Cleaning Pattern

Standard orbital pattern and adapted helix pattern





Both cleaning pattern were performed by adaptive cleaning device

Cleaning time until 5% soil residual: **Orbital Pattern: 1650 s** **Adapted Helix Pattern: 690 s**

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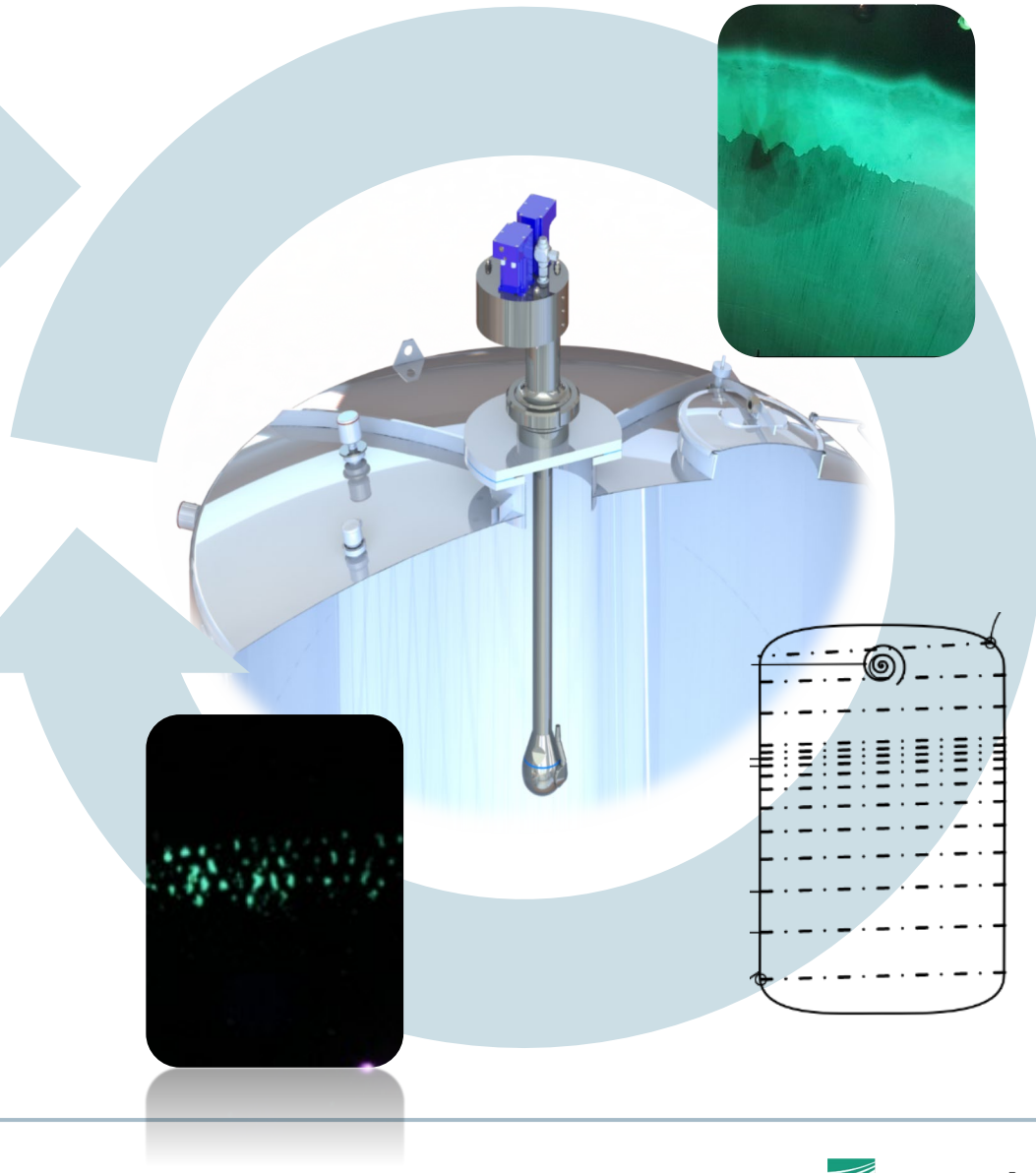
Level 2

A feedback-approach

Soiling Type	2
Dirty hold time	600
Cleaning fluid temperature	80

Principle Workflow:

1. Input: application and cleaning parameters (preoptimized program), process model
2. Detect soiling, (data on soiling properties)
3. adapted cleaning path and strategy for adaptive cleaning device based on fixed rules, (cleaning parameters)
4. verify remaining soiling, maybe back to 3



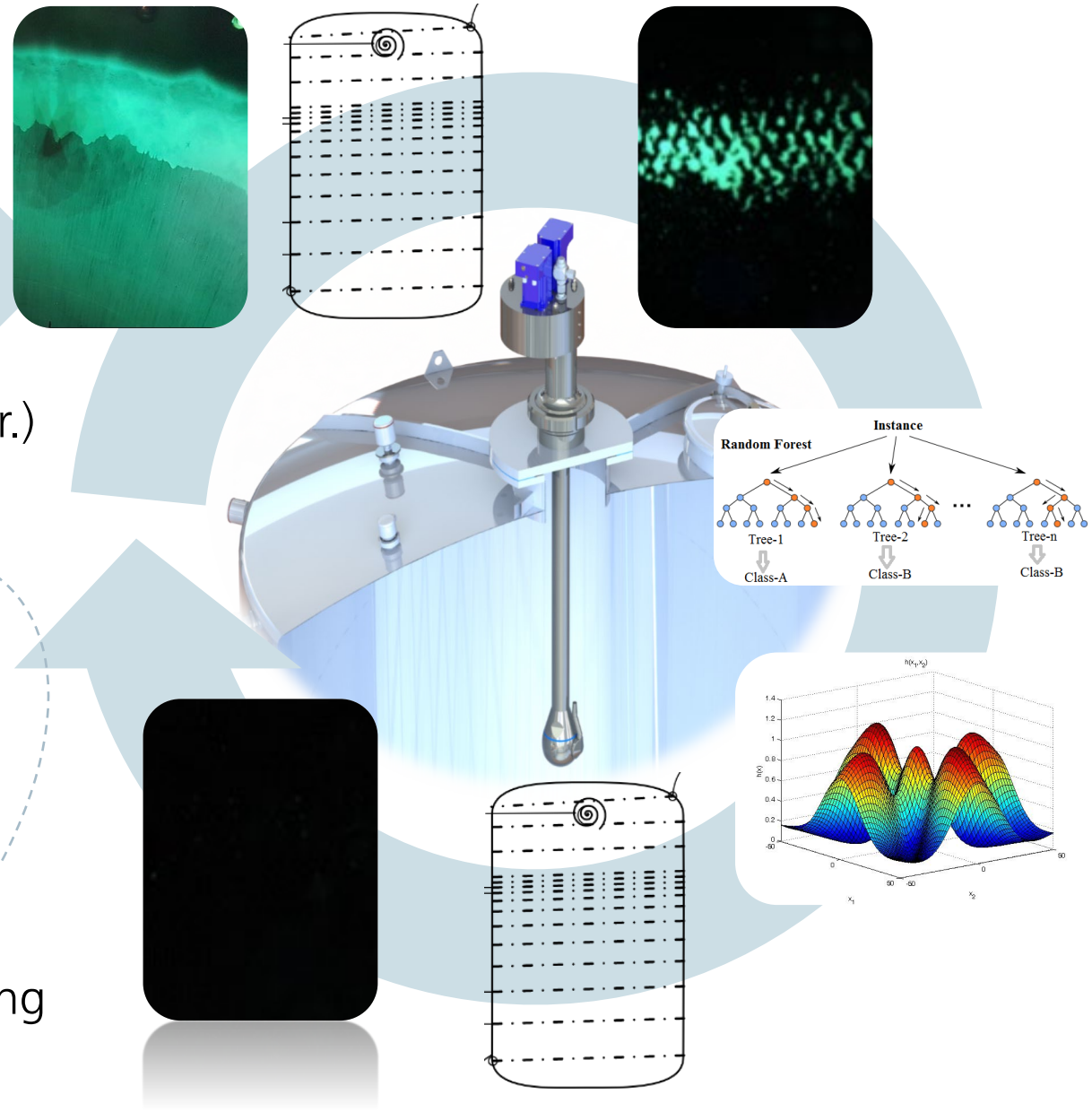
Level 3

A self-learning approach

Soiling Type	2
Dirty hold time	600
Cleaning fluid temperature	80

Principle Workflow:

1. Input: application and cleaning parameters (preo. pr.)
2. Detect soiling, (data on soiling properties)
3. Verify remaining soiling
4. Search for new optimum parameters based on trained model using methaheuristic optimization, calculate parameters, path planning, (cleaning parameters)
5. Run cleaning with new parameters, back to 2.
6. Clean vessel: Build model to map baseline to cleaning result



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Data driven modeling

Mapping parameters to cleaning result

Adaption of cleaning process data to machine learning algorithms

Create abstract features describing the process as feature vector

- Segmentized soiling / vessel surface area
- Pre-conditions and process parameters: soaking time, type of soiling, cleaning fluid, water pressure, …
- Geometric features: Position of the segment, angle of spray jet, …

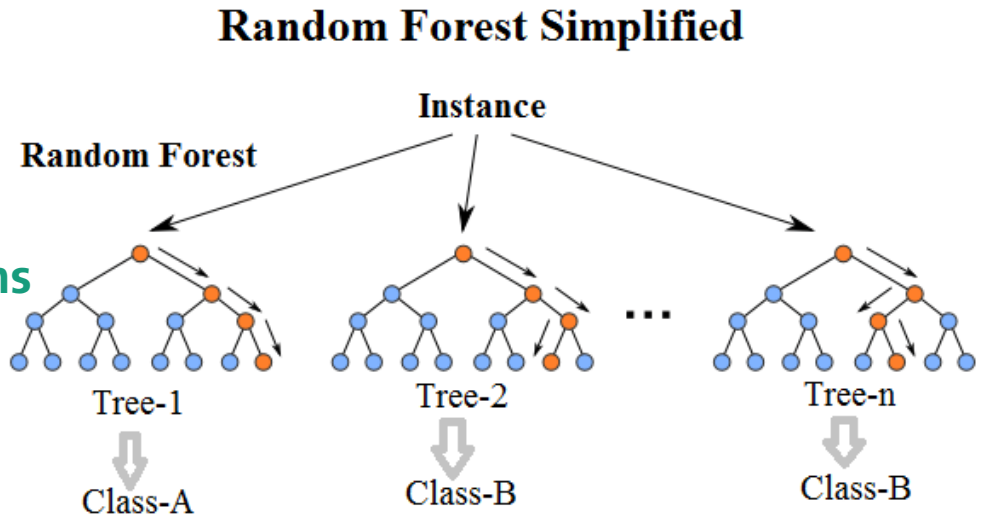
Build regression modell

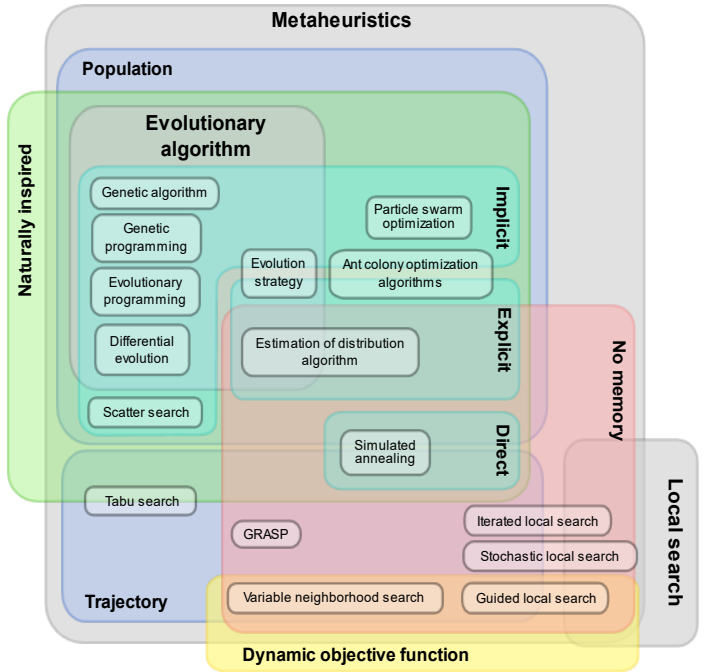
- Target Value: Cleaning result (Duration, ressources, success)
- Good results using Random Forest Regression

Optimisation

- Favorits…so far: Evolutionary algorithms

The challenge is transferability → dimensionless parameters, federated learning





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Summary

High potential – still some steps to go

- CPCS: opportunity for adaptive, efficient, and safe cleaning processes
- Level 1: only the mechanical adaptivity of the ADC was used to optimize, based on individual experience
- Level 2 or 3: requires trustworthy algorithms or models to control cleaning processes
- Data driven approaches / machine learning algorithm seems to be promising
  - challenges: e.g.: generalization for different types of soils, models of cleaning process, transfer of lab scale results to industrial processes
- Application of machine learning depends on qualified training data for creating the models
  - current challenge of small volumes of training data
    - approaches: learning on small data sets, few-shot-learning

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Thank you for your attention

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