SMaRT-Online WDN

Online Security Management and Reliability Toolkit for Water Distribution Networks

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Event Detection Module -

Water Quality Supervision of Distribution Networks based on Machine Learning Algorithms

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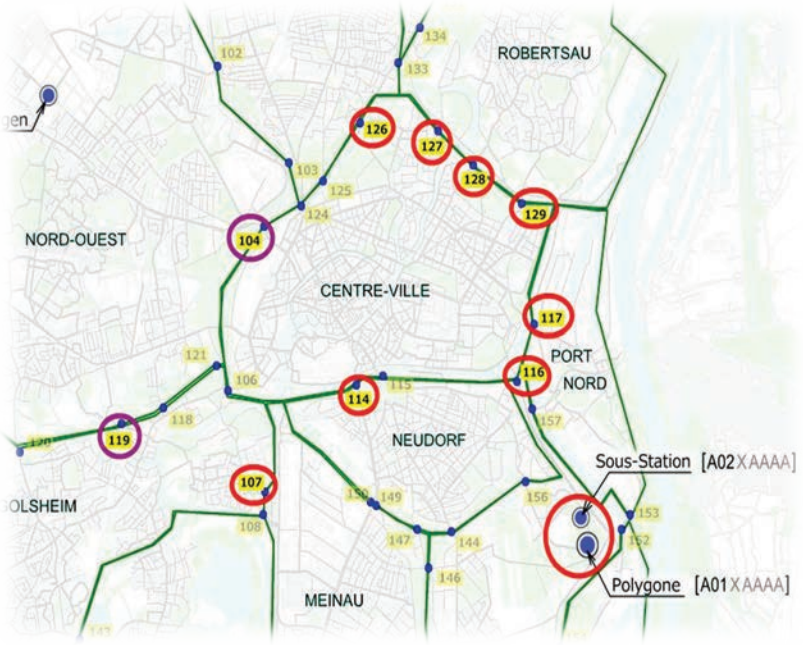
Motivation

- Large amount of quality sensors placed in water distribution network (WDN)
- Sensors are used to monitor if a contamination has occurred in the network
- **Problem: Too many sensors for manual supervision by operators**
  Thresholds of quality parameters depend on e.g. water sources, operational modes
- **Solution: Data-driven event detection concept**



Part of Strasbourg's Water Distribution Network

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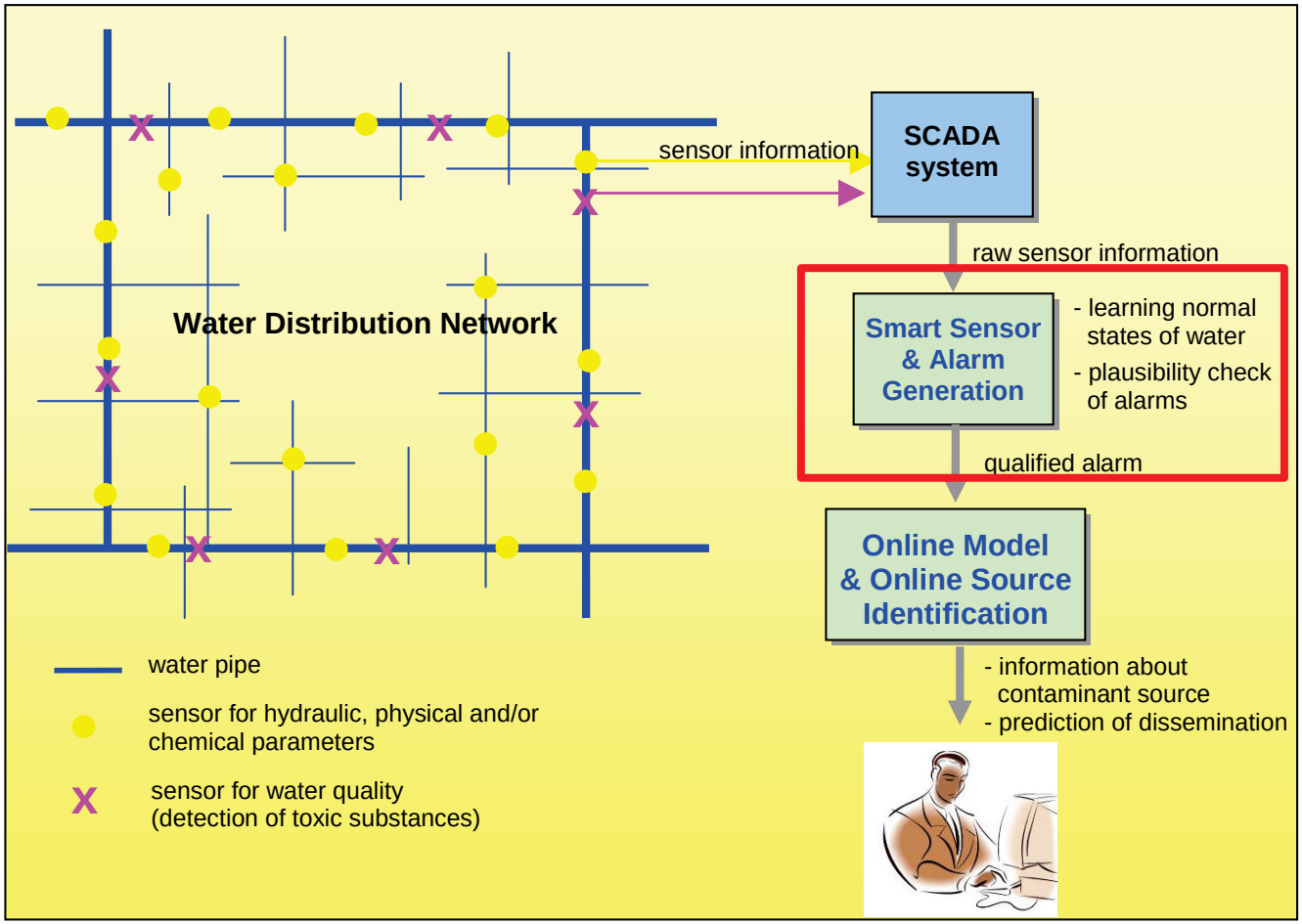
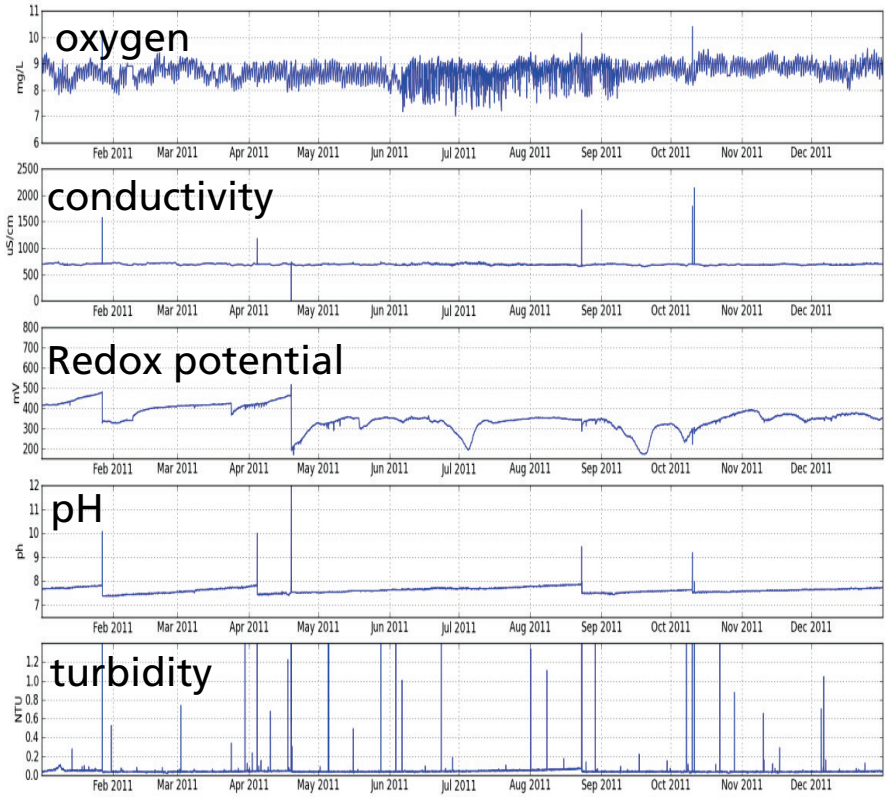
Motivation

- Aim: Online detection of contamination events with low false alarm rate

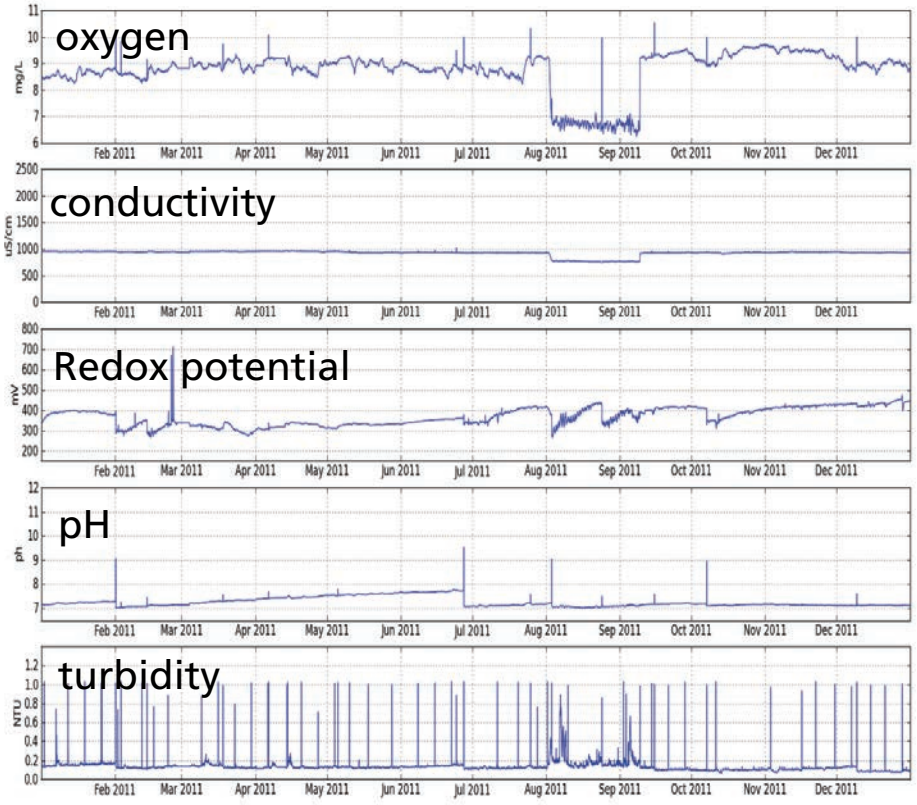


Real Water Quality Data are complex….

Berlin Station 1 (2011)



Berlin Station 2 (2011)



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Expectations to Event Detection Module

- **Highly sensitive, but very low number of false alarms**
- Operator knowledge about water properties, sensor properties, operational modes can be included easily (**Operator Feedback**)

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- Consideration of several water quality parameters (**mulivariate approach**)
- Only few parameters for fine tuning necessary (**self-learning approach**)

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- Operator knowledge about water properties, sensor properties, operational modes can be included easily (**Operator Feedback**)
- Consideration of several water quality parameters (**mulivariate approach**)
- Only few parameters for fine tuning necessary (**self-learning approach**)
- Module can be easily applied to a large number of different measurement stations
- Detected events are interpreatable (**no “black box” aproaches**)

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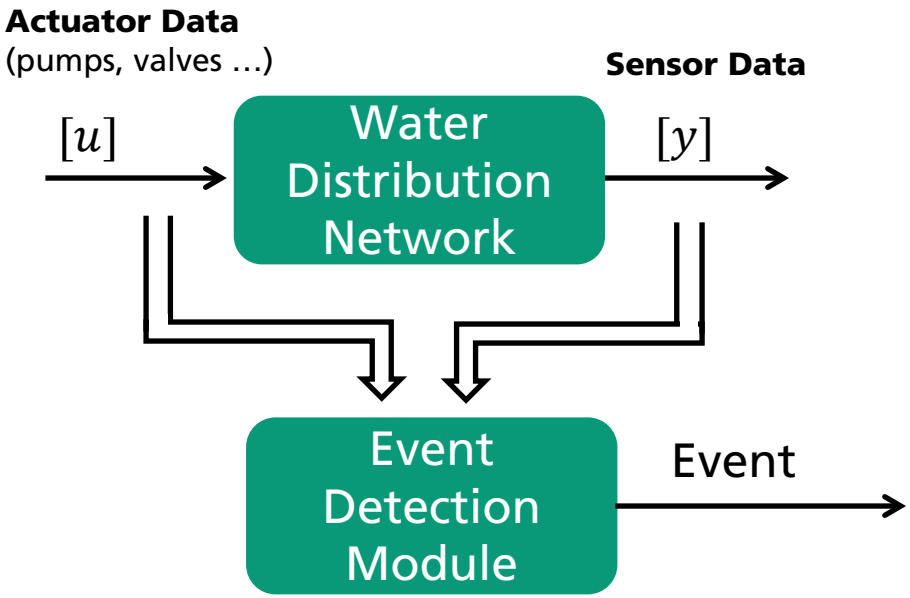
Event Detection Module

General approach of data-driven novelty detection



Offline

- Training of multivariate process model with sensor data of “normal states”
- Store model as “normal” process condition

Online

- An “Event” is a new, unknown state of the process
- Each time a new sample is acquired, the process model calculates if an event occurres

Event Detection Module

Step 1: Data Preprocessing (offline and online)

- Outlier filtering
- Smoothing of the measurements (e.g. by moving average filter)
- Normalization of the measurements

Step 2: Training of "normal" Model (Offline)

- Calculating Principal Components (PCA)
- Generation of an alarm threshold

Step 3: Calculation of an Alarm Index (Online)

- If alarm index is above threshold
  → EVENT (has to be confirmed by operators!)

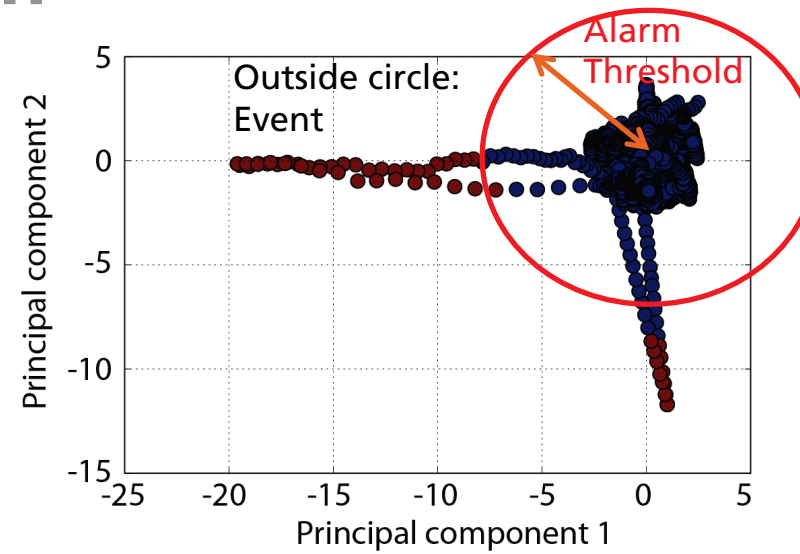
Step 4: Re-Train Model after Operator Feedback (Offline)

- In case of false (positive/negative) alarm:
  Prepare new training data, go to Step 2

Event Detection Algorithm

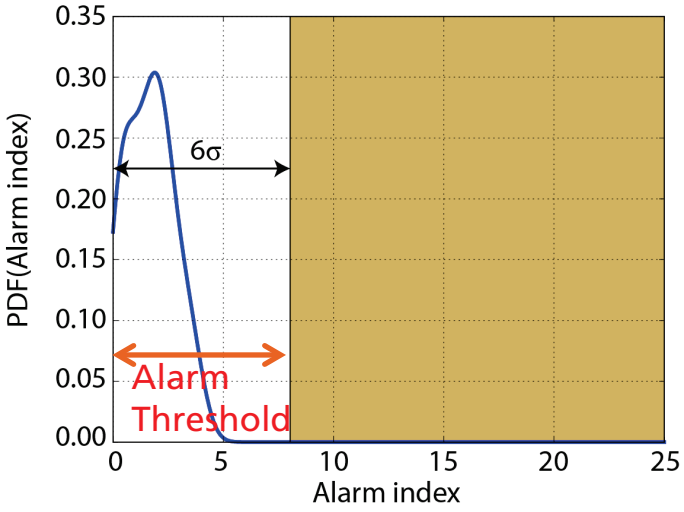
Calculation of alarm index (offline / online)

- Based on Principal Components Analysis (PCA)
- First two principal components describe "state trajectory" of the measurement station
- Distance to center point describes value of alarm index



Determination of alarm threshold (offline)

- Calculate alarm index using training data
- Calculate N-σ environment of alarm index
  (σ : standard deviation, N: fit parameter, e.g. N = 6)
- Use value as threshold for event detection



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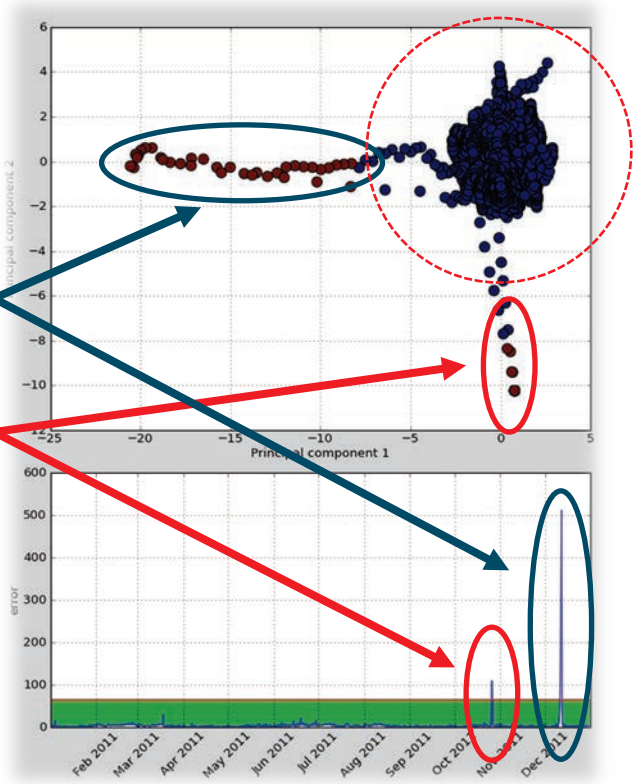
Event Detection Algorithm

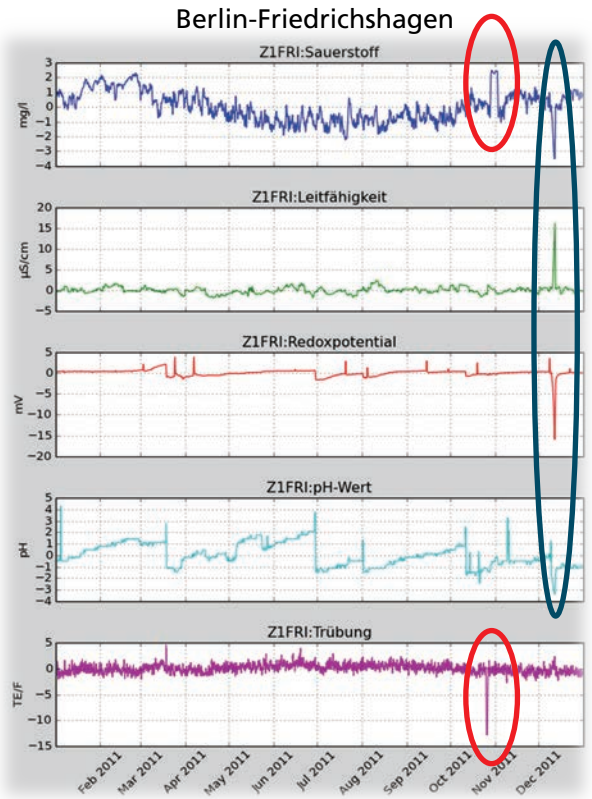
Results from Berliner Wasserbetriebe (BWB)

Event 1

Event 2



Berlin-Friedrichshagen



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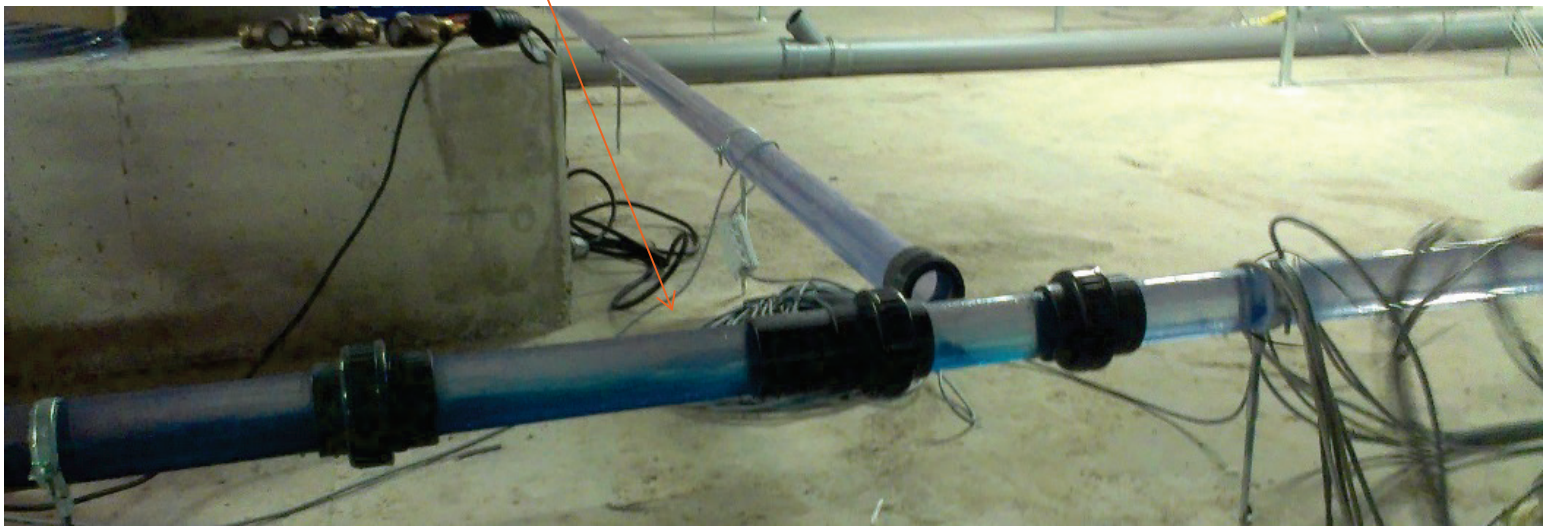
Experimental Tests at Laboratory Plant

Test Network at TZW (Dresden)

“Contaminant”: Indigo carmine with salt

Injected “contamination”



Injection pump

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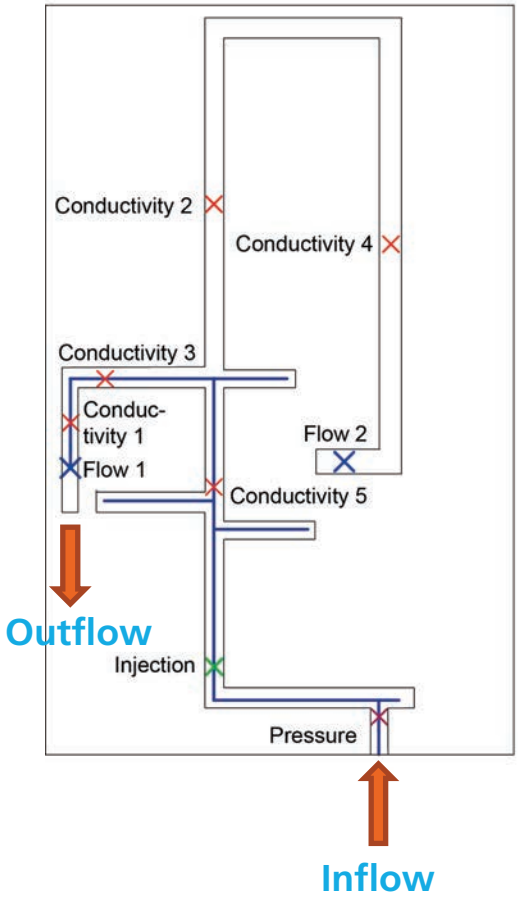
Setup of two Flow Configurations

Flow Configuration 1



Sensor Equipment

- 5 Conductivity sensors
- 1 Pressure sensor
- 2 Flow sensors

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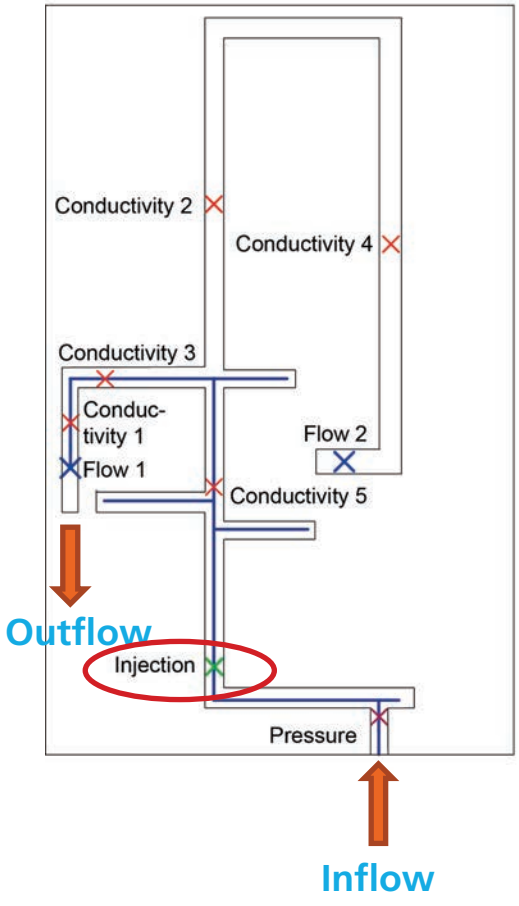
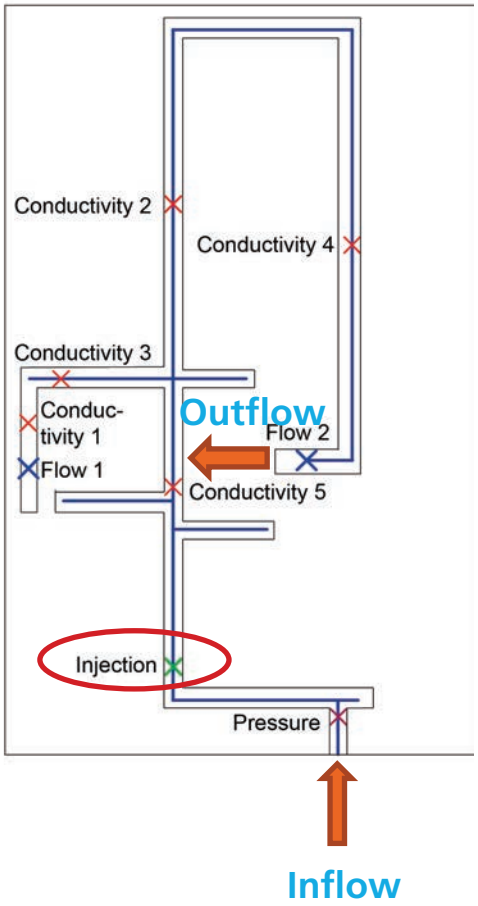
Setup of two Flow Configurations

Flow Configuration 1



Flow Configuration 2



Sensor Equipment

- 5 Conductivity sensors
- 1 Pressure sensor
- 2 Flow sensors

Four Data sets (time series):

Normal water configuration 1

Contaminated water config. 1

Normal water configuration 2

Contaminated water config 2

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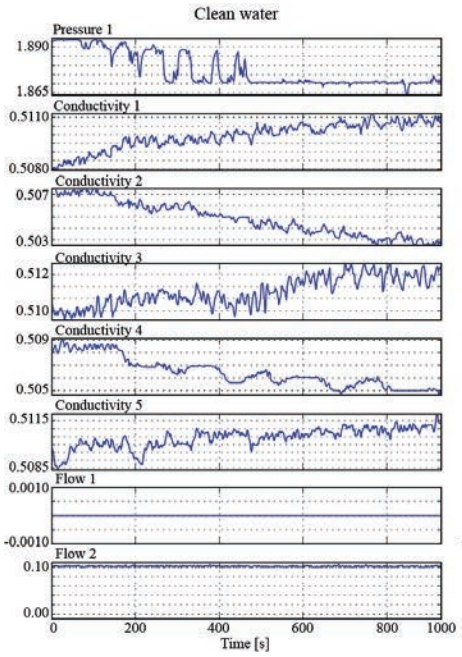
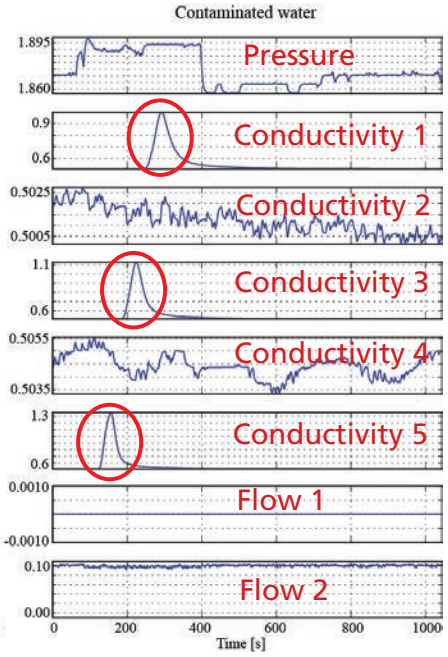
Flow Configuration 1

Normal Water 1

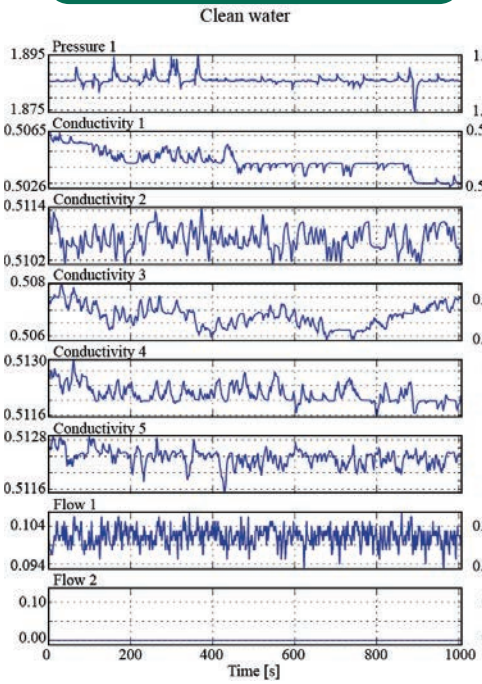


Contaminated Water 1

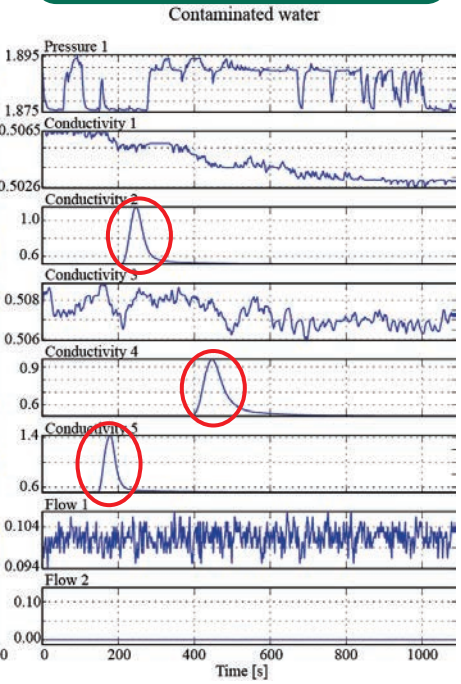


Flow Configuration 2

Normal Water 2



Contaminated Water 2



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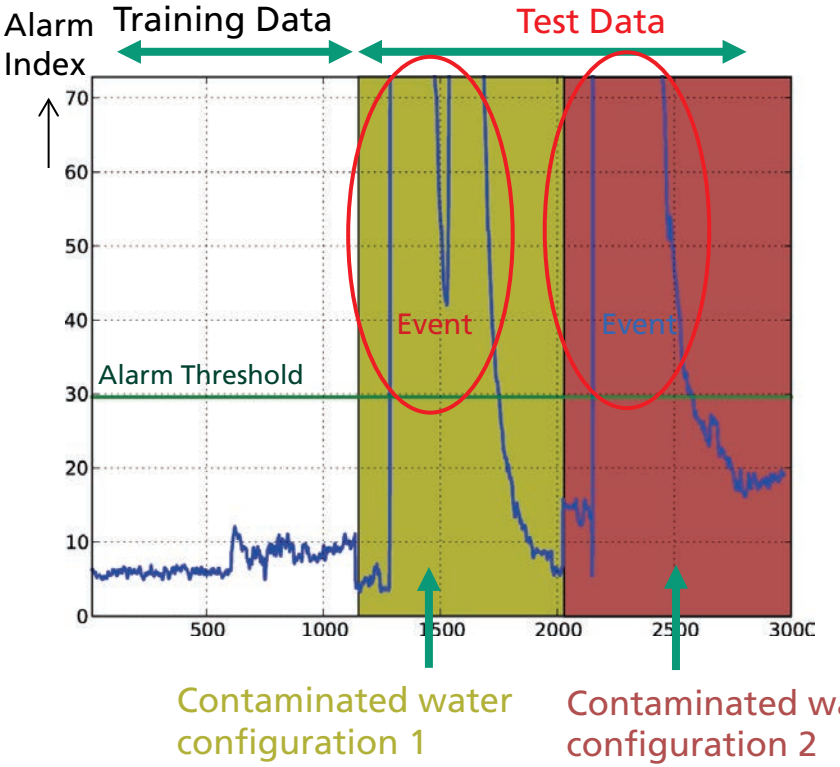
Training/Test Scenario 1

- Training Data: *Normal 1, Normal 2*
- Test Data: *Contaminated 1, Contam. 2*

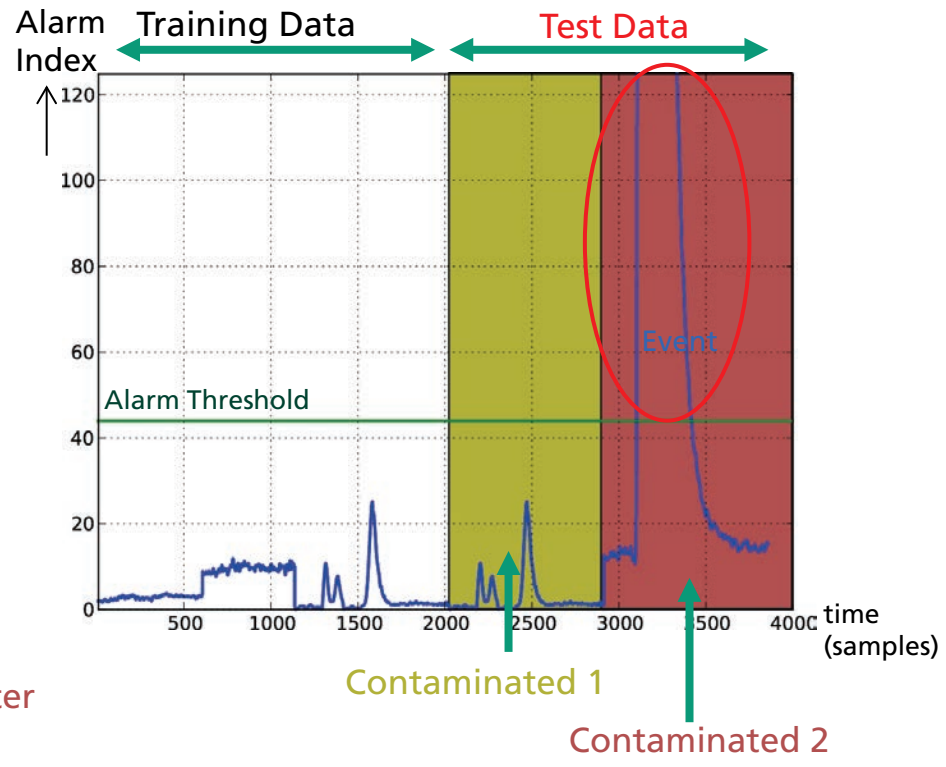
→ **Event found at contamination 1 + 2**



Training/Test Scenario 2

- Training Data: *Normal 1, Normal 2, Contaminated 1*
- Test Data: *Contaminated 1, Contam. 2*

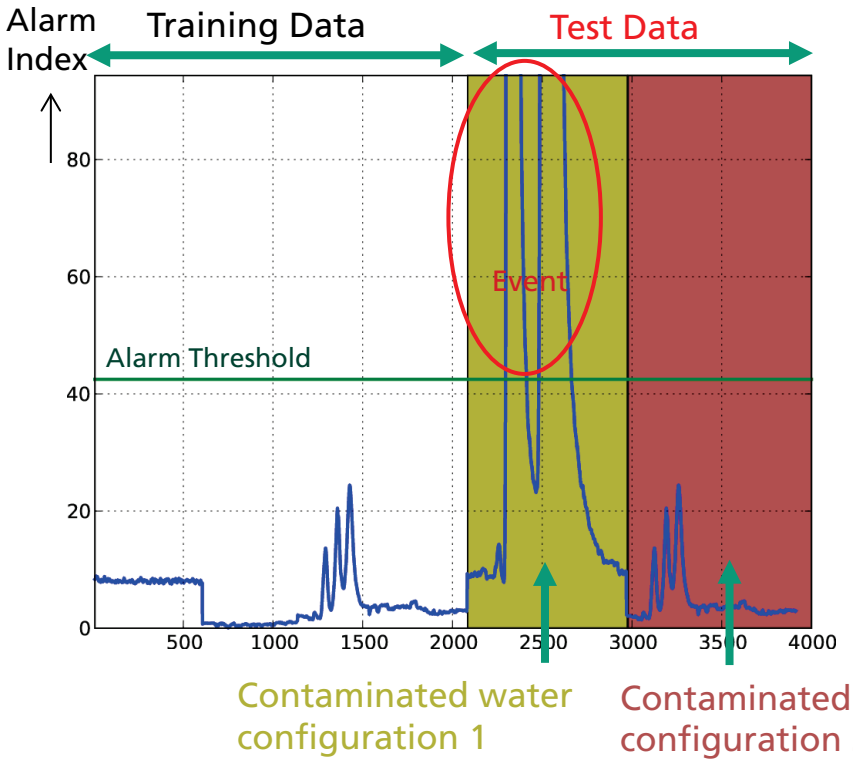
→ **Event found only at contamination 2**



Training/Test Scenario 3

- Training Data: *Normal 1, Normal 2, Contaminated 2*
- Test Data: *Contaminated 1, Contam. 2*

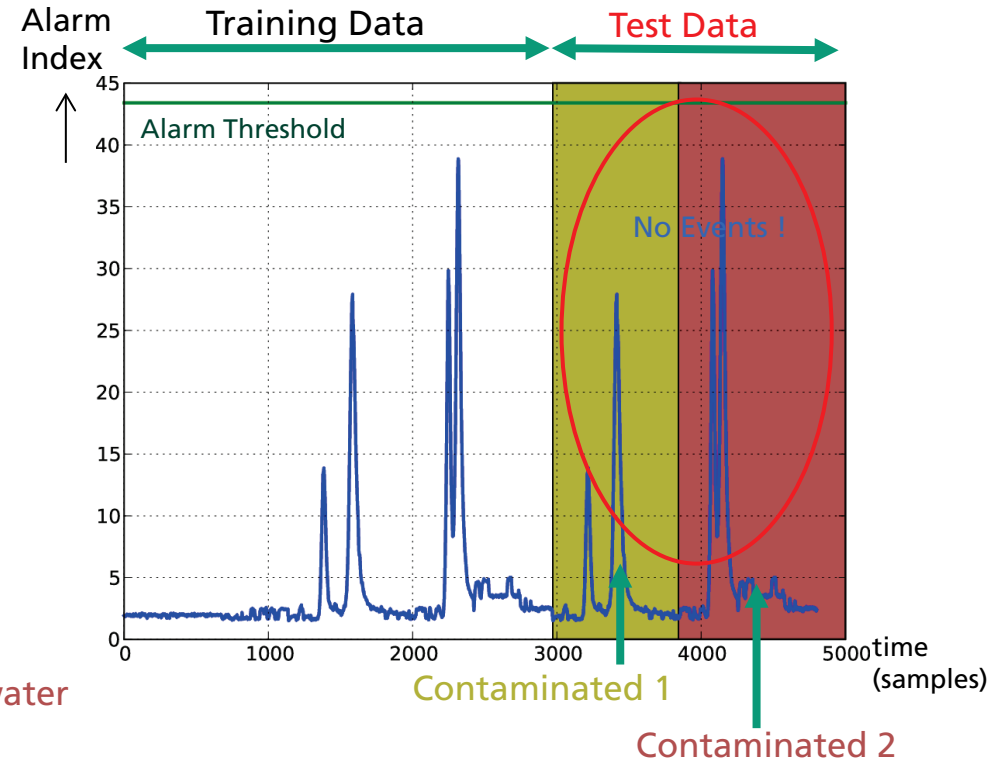
→ **Event found only at contamination 1**



Training/Test Scenario 4

- Training Data: *Normal 1, Normal 2, Contaminated 1, Contaminated 2*
- Test Data: *Contaminated 1, Contam. 2*

→ **No Event found!**



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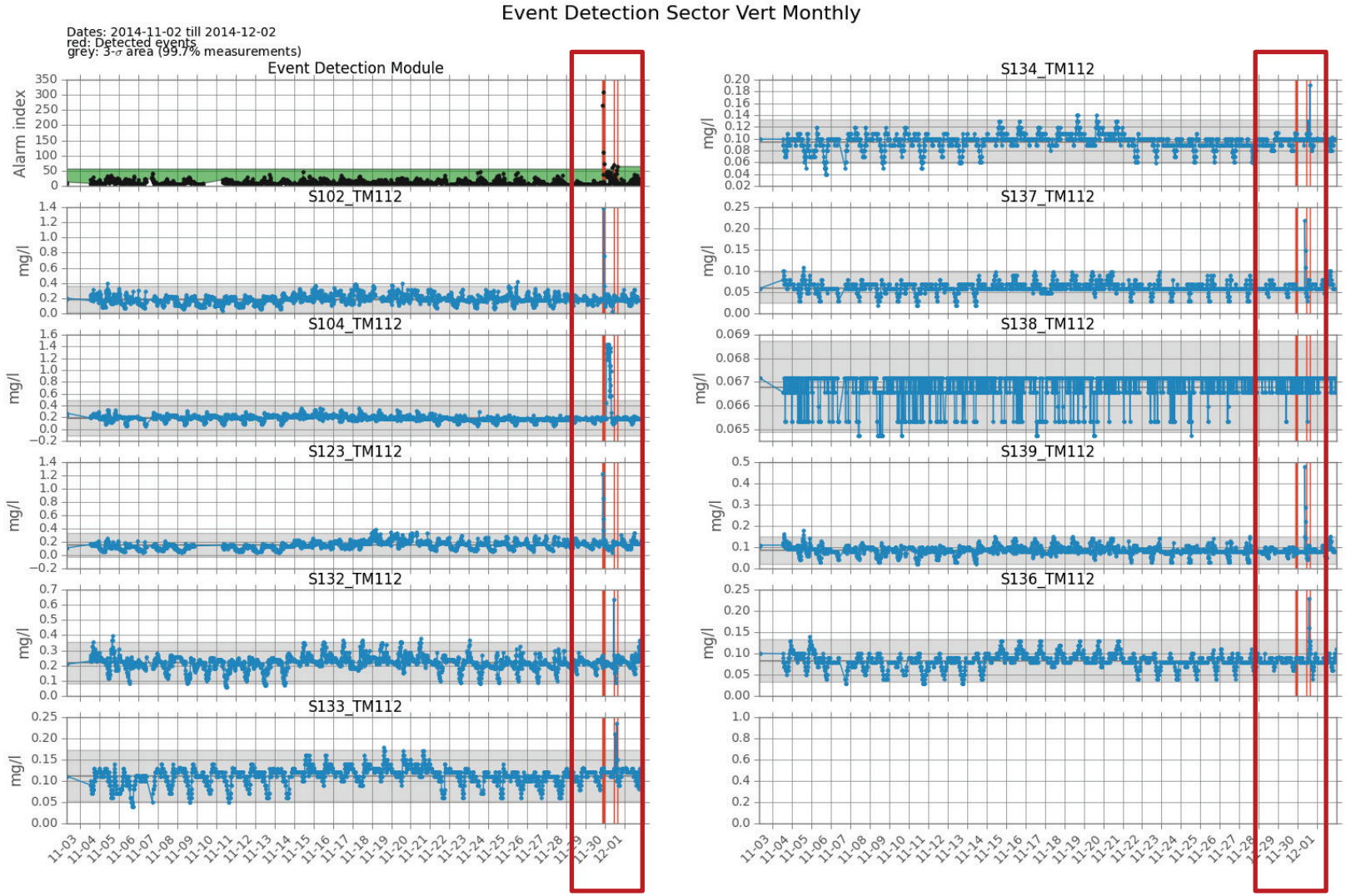
Event Detection in Real World Data (1)

- Data from Strasbourg (CUS), 11/2014
- Propagation of chlorine peak through the network



Event Detection in Real World Data (2)

- Data from Paris (SEDIF), 9.4.2014
- Strong decay of free chlorine (due to change of water source)

Reported event

Pilote QUALIO – Anomalie Kapta

Référence : VILJU 09-04-2014

Description de l'évènement

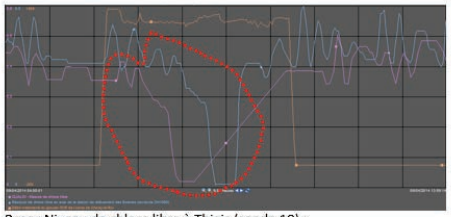
Décalage de temps entre la chute de niveau de chlore des Sorbiers DN1000 et Thiais, le 09/04/2014 de 07h40 à 9h20.

Sites concernés : THIAICSR01MP01

Localisation des anomalies

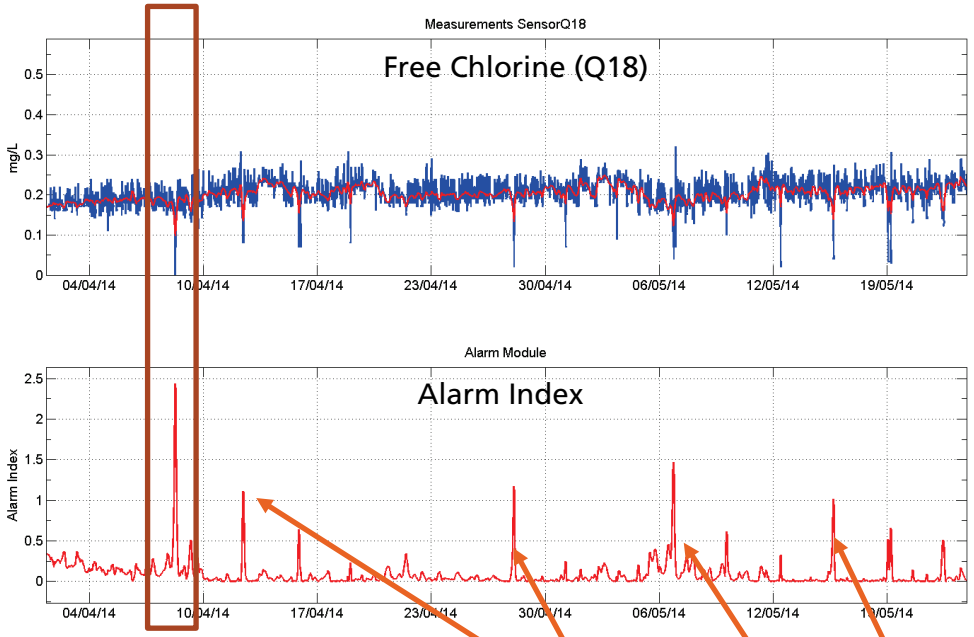
Localisation de l'incident
Kapta

Courbes Kapta de chlore libre



Rose : Niveau de chlore libre à Thiais (sonde 18) ;
Bleu : Résiduel de chlore libre en aval de la station des Sorbiers (DN1000) ;
Orange : Débit instantané de GV5.

Measurements / Resulting alarm index



Reported event

Similar events

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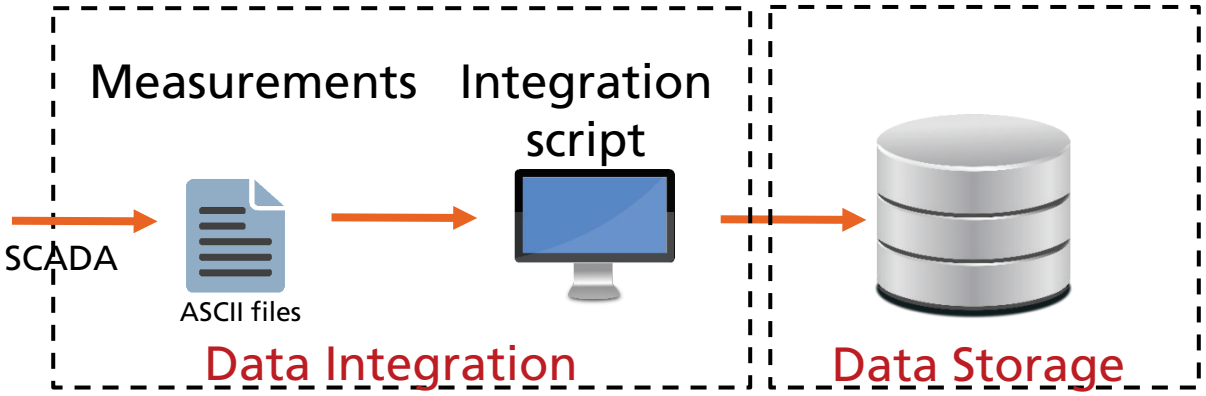
Implementation as real-time Software (1)

- Automated data integration and plot generation (data+events)
- Results of Event Detection Module (events) are stored in database



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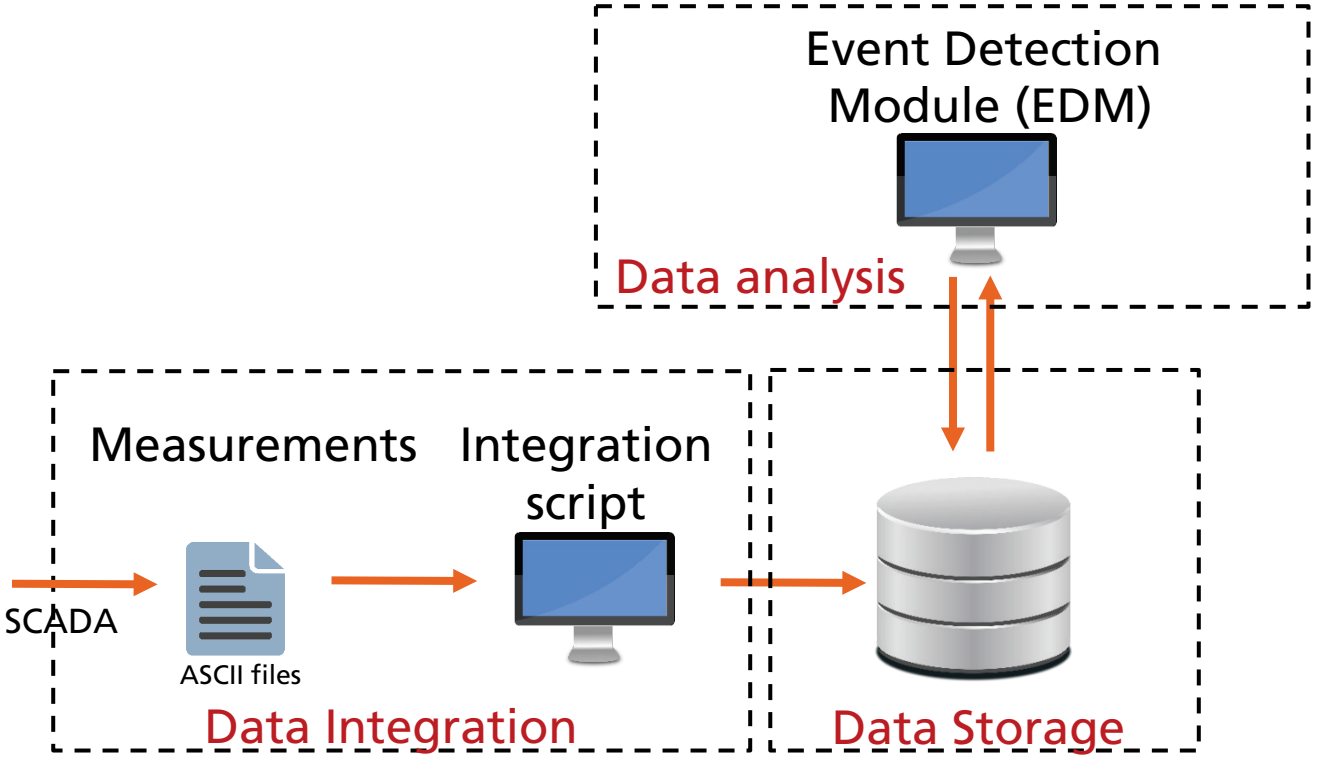

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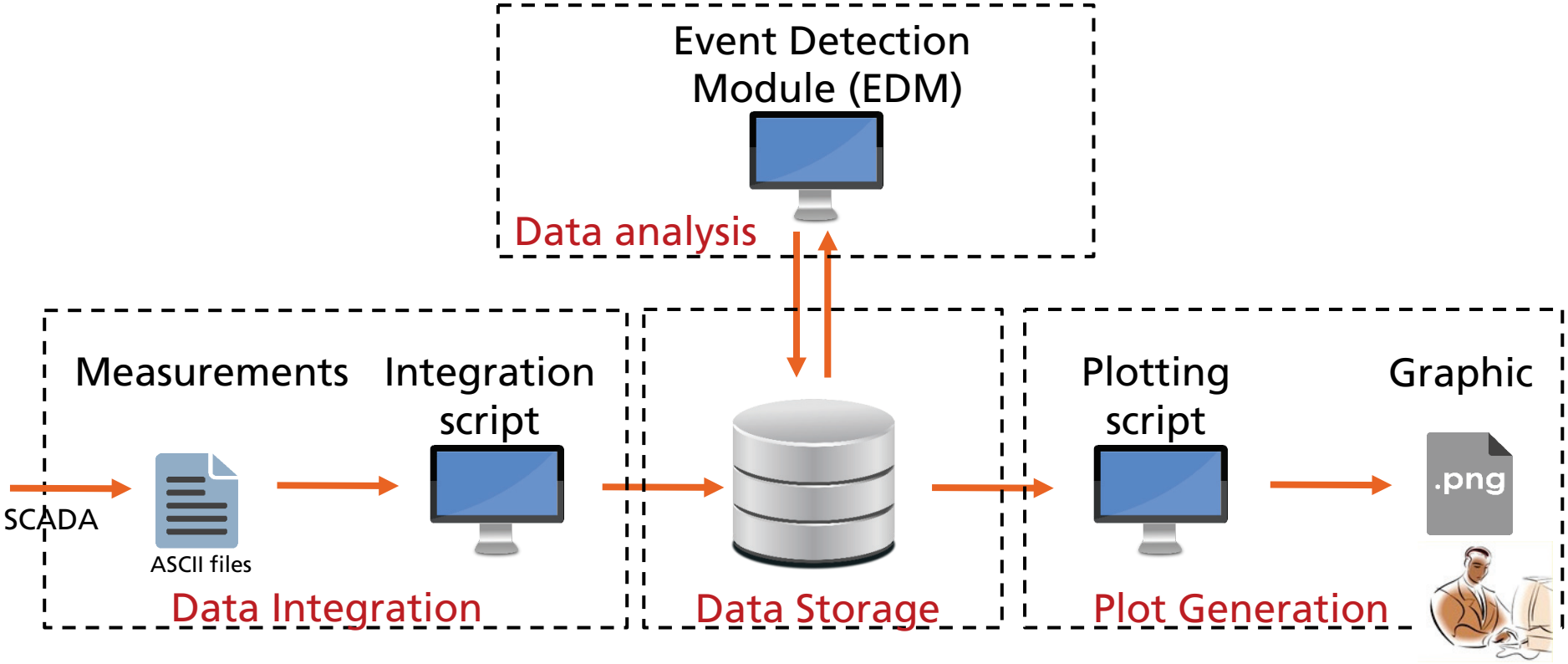

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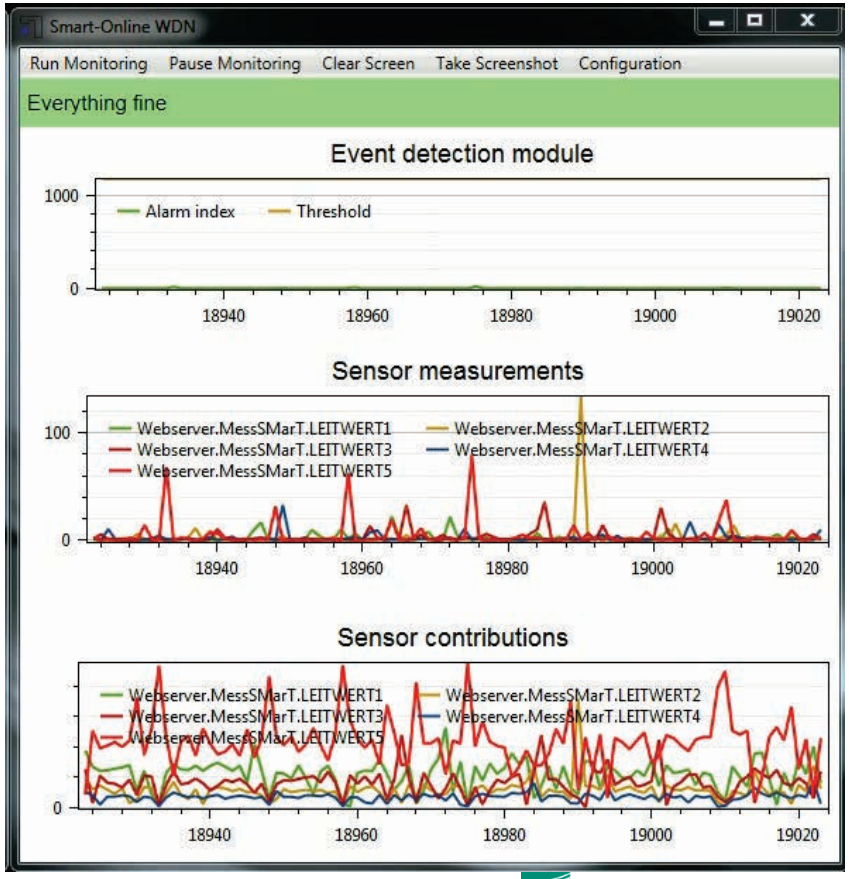
Implementation as real-time Software (2)

- Software communicates over OPC server
- Activates other modules can be started (contamination source identification, look ahead simulation, planning of mitigation measures …)



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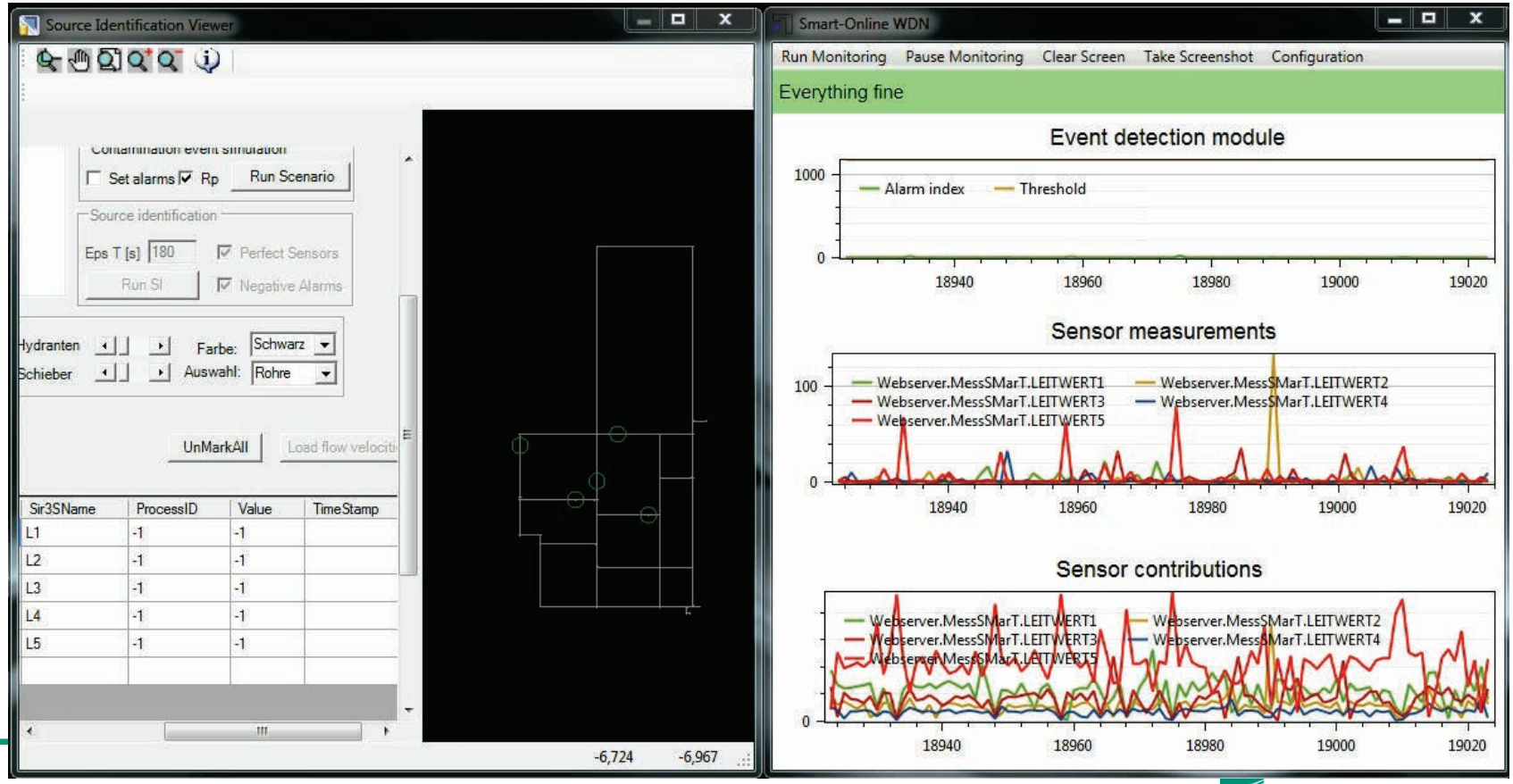

Summary

- Data-driven real-time event detection concept for water distribution networks based on Principal Components Analysis (PCA)
- Only one fitting parameter (N-σ environment for alarm threshold)
- Implemented as real-time capable software
- Tested by means of historical data of Berlin, Paris, Strasbourg and online at a laboratory plant

Future research

- Incremental learning (consideration e.g. of long term drifts)
- Plausiblity check of events by hydraulic and quality model
- Use information about water source and operational information

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Thanks for your attention!

Project website: www.smart-onlinewdn.eu

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