Application of the Enhanced Dynamic Causal Digraph Method to Wastewater Treatment Process

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Motivations

Wastewater treatment (WWT) process is a complicated process where sensors and equipment are operated at harsh conditions

Tremendous scope for improvement of fault detection and isolation methods

Benefits

- reduce monitoring costs
- consistent water quality monitoring
- increased consistency by rapid detection and correction of faults
- reduction in human errors

Objective

Apply Enhanced Dynamic Causal Digraph Method to Wastewater Treatment Processes for **Fault Diagnosis**

The Enhanced Dynamic Causal Digraph Method

Process knowledge and simulation software are the only pre-requisites to test the method

Process Study

The proposed method performs the fault detection and isolation as follows:

1. Causal Digraph Modeling
2. Fault Scenarios Study
   - Process Fault
   - Sensor Fault
3. Fault Diagnosis
   - Generate the global (GR) and local residuals (LR)
   - Detect a possible abnormality in the residual signals
   - Locate the primary fault and identify its nature by means of the fault isolation and nature rules
4. Analysis of Results

Outline

Process Study

Causal Digraph Model

Fault Scenarios

Fault Diagnosis

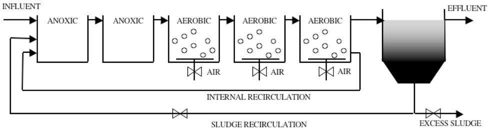
Conclusions

Process Description

Inside a biological WWT plant, the **Activated Sludge Process** (ASP) is the most common used technology to remove organic pollutant from wastewater

Benchmark Simulation Model No.1 (BSM1) proposed by the IWA-COST group

Nitrogen and Carbon Compounds Removal



The BSM1 characterizes the plant including plant layout, specific model parameters and a detailed description of the influent flowrate and compositions

Process Models

The benchmark is based on two internationally accepted process models

Settler

- Thickening and clarification processes take place here
- It is modelled as a stack of layer by means of the **Takacs Model**

Bioreactor

- It consists of two anoxic (**Denitrification**) followed by three aerobic (**Nitrification**) zones
- They are modelled with the **Activated Sludge Model No.1**

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Autotrophic Bacteria

Heterotrophic Bacteria

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$$\mu(S) = \hat{\mu}\frac{S}{K_S + S}$$

Process Models

The ASM1 consists of 13 state variables and 8 process reactions

S_I	Soluble inert organic matter
S_S	Readily biodegradable substrate
X_I	Particulate inert organic matter
X_S	Slowly biodegradable substrate
X_{BH}	Active heterotrophic biomass
X_{BA}	Active autotrophic biomass
X_P	Part. prod. from biomass decay
S_O	Dissolved Oxygen
S_{NO}	Nitrite and Nitrate Nitrogen
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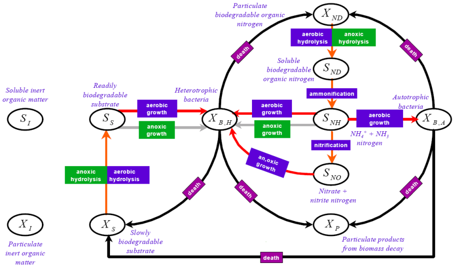
S_{ALK}	Alkalinity



Composite variables

$$COD = S_I + S_S + X_I + X_S + X_{BH} + X_{BA} + X_P$$
$$TSS = 0.75(X_I + X_S + X_{BH} + X_{BA} + X_P)$$

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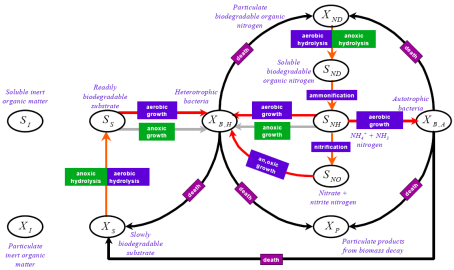

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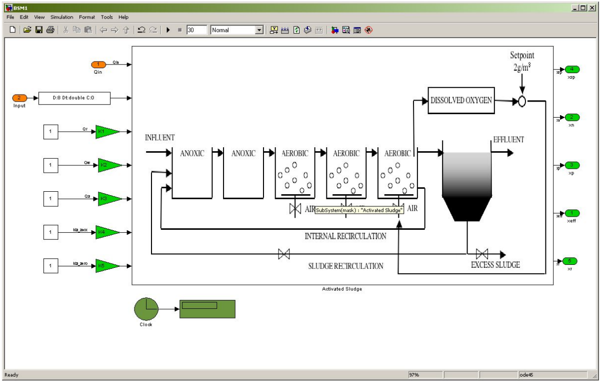
In the secondary settler model all the particulate components are lumped together

Process Simulation

Bioreactor and settler are coupled together in Matlab/Simulink

Testing environment for the enhanced dynamic causal digraph method



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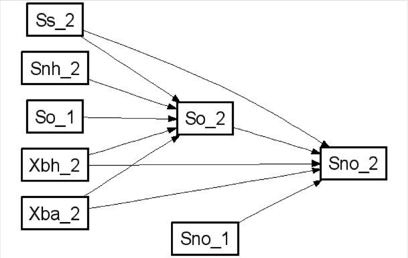

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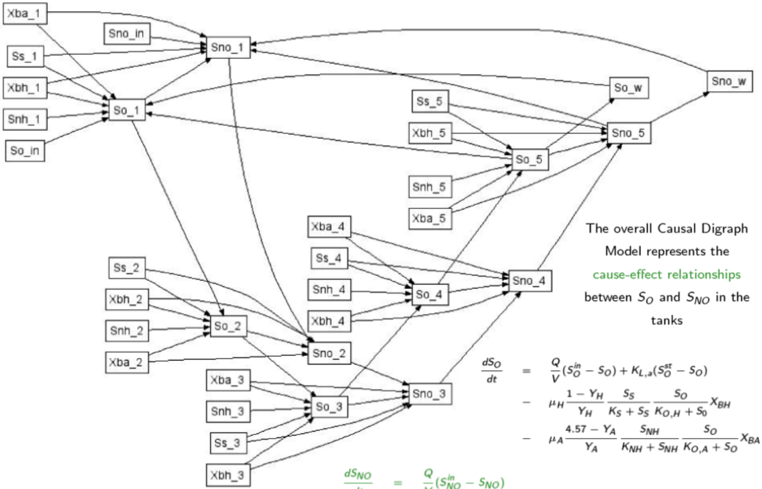

The overall Causal Digraph Model represents the cause-effect relationships between S_O and S_{NO} in the tanks

$$
\begin{aligned}
\frac{dS_O}{dt} &= \frac{Q}{V}(S_O^{in} - S_O) + K_{L,a}(S_O^{st} - S_O) \\
&- \mu_H \frac{1 - Y_H}{Y_H} \frac{S_S}{K_S + S_S} \frac{S_O}{K_{O,H} + S_O} X_{BH} \\
&- \mu_A \frac{4.57 - Y_A}{Y_A} \frac{S_{NH}}{K_{NH} + S_{NH}} \frac{S_O}{K_{O,A} + S_O} X_{BA}
\end{aligned}
$$

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\begin{aligned}
\frac{dS_{NO}}{dt} &= \frac{Q}{V}(S_{NO}^{in} - S_{NO}) \\
&- \mu_H \frac{1 - Y_H}{2.86 Y_H} \frac{S_S}{K_S + S_S} \frac{K_{O,H}}{K_{O,H} + S_O} \frac{S_O}{K_{NO} + S_{NO}} \eta_g X_{BH} \\
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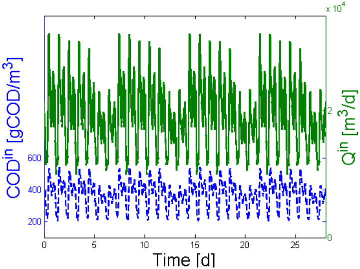
- 28 days are simulated with the influent flow and load compositions provided in the BSM1
- 2 faulty days are considered (14-16)



Two fault scenarios were selected to study based on the process knowledge

Scenario I

The change in the biomass growth rate due of high concentration of toxic metal in the influent wastewater is considered

Scenario II

The fault of the oxygen sensor is represented and analyzed

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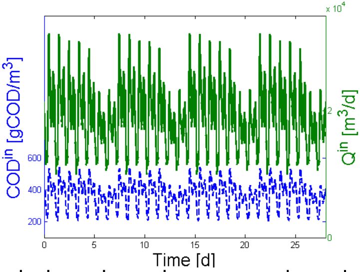

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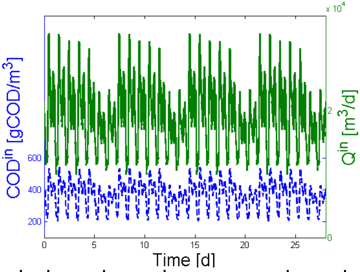

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Sensor Fault

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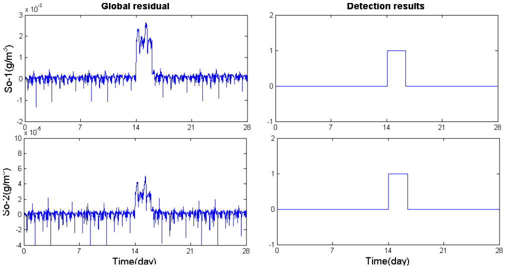
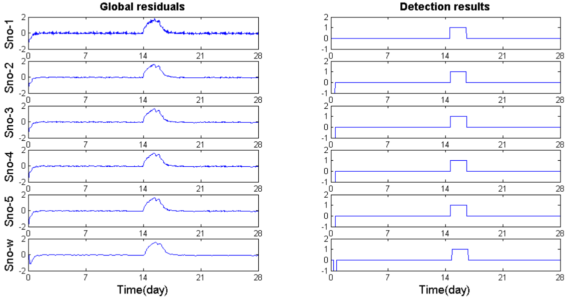
Global Residuals

are calculated for

S_O and S_{NO}



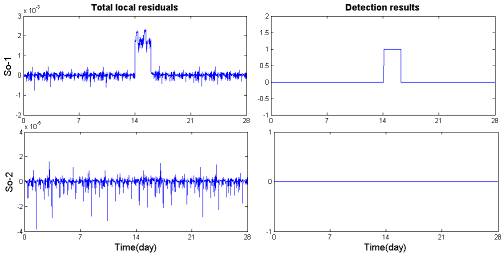


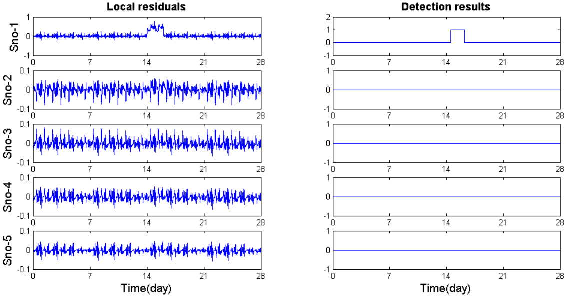
Diagnosis Results for Fault Scenario I

Local Residuals

are calculated for

S_O and S_{NO}





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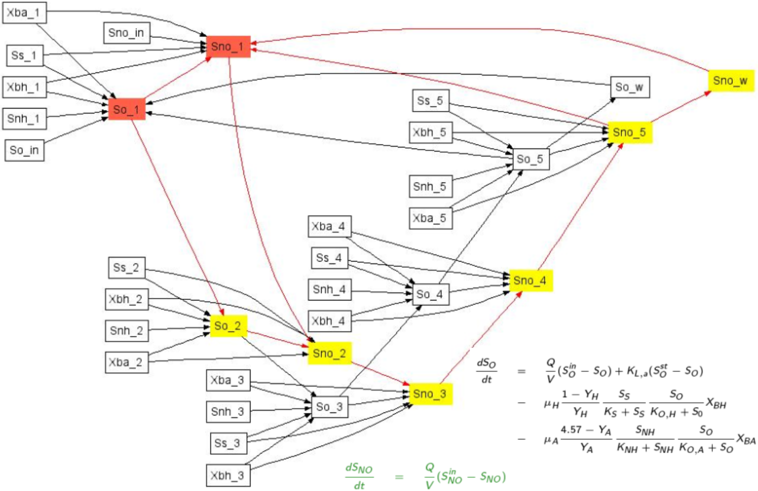

$$\begin{aligned}\frac{dS_O}{dt} &= \frac{Q}{V}(S_O^{in} - S_O) + K_{L,a}(S_O^{st} - S_O) \\ &- \mu_H \frac{1 - Y_H}{Y_H} \frac{S_S}{K_S + S_S} \frac{S_O}{K_{O,H} + S_0} X_{BH} \\ &- \mu_A \frac{4.57 - Y_A}{Y_A} \frac{S_{NH}}{K_{NH} + S_{NH}} \frac{S_O}{K_{O,A} + S_O} X_{BA}\end{aligned}$$

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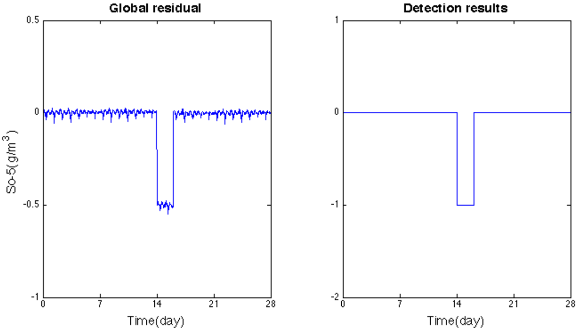
Diagnosis Results for Fault Scenario II

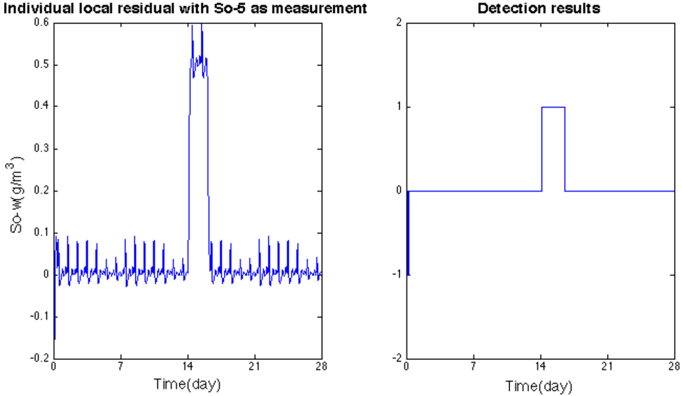
Global Residuals



Only variable $S_{O,5}$ is detected

Diagnosis Results for Fault Scenario II

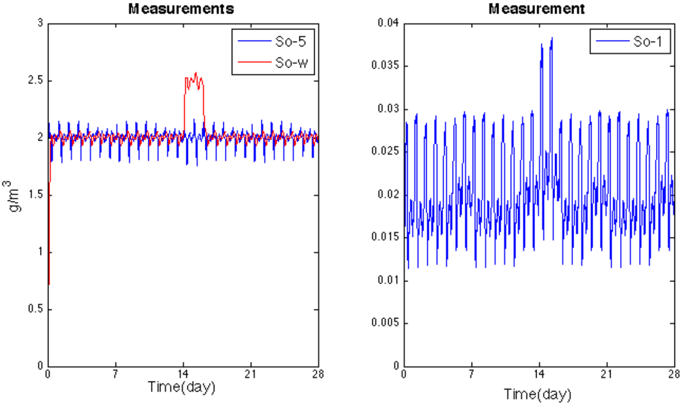
Local Residuals



The individual local residual for variable $S_{O,w}$ with the input $S_{O,5}$ as measurement was detected. This implies that the fault on the variable $S_{O,5}$ is a **measurement fault**

Diagnosis Results for Fault Scenario II

From the measurements for variables $S_{O,5}$, $S_{O,w}$ and $S_{O,1}$, it can be seen that during the days 14-16, the variables $S_{O,w}$, $S_{O,1}$ seem to have the fault, but actually the method is able to find the real fault in on the sensor of the $S_{O,5}$



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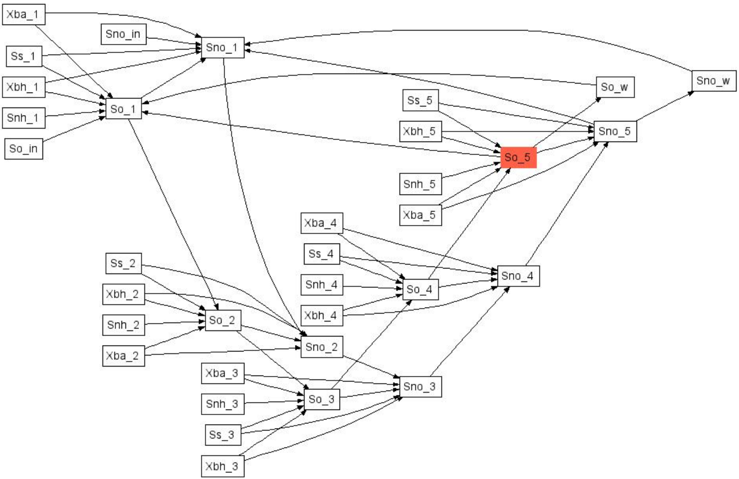

Outline

Conclusions

The enhanced casual digraph reasoning method for fault diagnosis was applied to the activated sludge process

Two fault scenarios were tested

Process fault

The method was able to handle it

Sensor fault

The correct node was detected

Future Development

- The preliminary study is limited by the assumption that the toxic affects only one tank. In future μ fault in different tanks can be considered and FTC strategy can be designed
- The estimated size of the sensor fault can be used to design FTC for the aeration controller