Identification of analytical redundancy relations. Application to sensor fault diagnosis of a wastewater treatment station

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Workshop on Advanced Control and Diagnosis 2006.

Context

Stricter European standards

Difficulties for the station to respect this standards, links to :

- process perturbations
- sensors dysfunction

Importance of faults detection and isolation

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Diagnostic by analytical redundancy

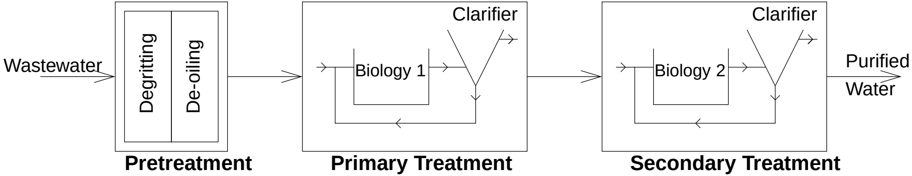
coherence test between a measurement and its estimate provided by a model
$\longrightarrow$ Search for redundancies relations

Plan

Bleesbrück station

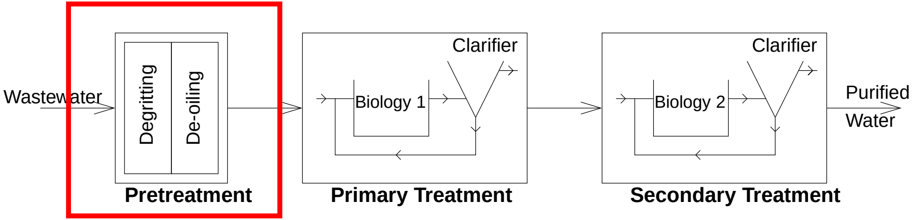
Activated sludge wastewater treatment station

Activated sludge wastewater treatment station



Bleesbrück station

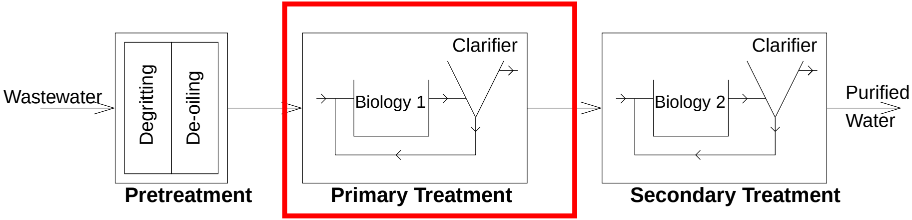
Activated sludge wastewater treatment station



- Elimination of all components which could disturb the treatment

Bleesbrück station

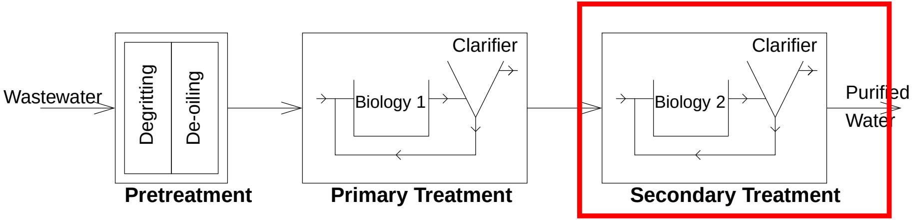
Activated sludge wastewater treatment station



- Elimination of organic pollution and phosphorus

N°	Position	Name	Measure type
1	Before biology 1	Q_{in}	Flow
2		T	Temperature
3		σ	Conductivity
4		A	UV absorption
5		PH	PH
6	In biology 1	$MES1$	Suspended matter
7		$O1$	Dissolved oxygen
8	After biology 1	$NH1$	Ammonium
9		$NO1$	Nitrate
10		$OP1$	Orthophosphate

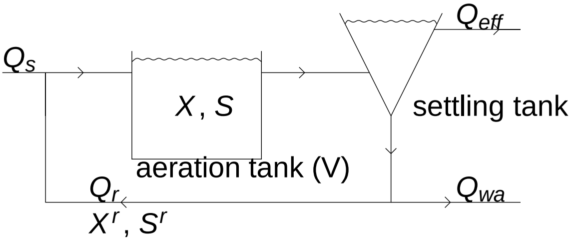
Activated sludge wastewater treatment station



- Elimination of nitrognized pollution

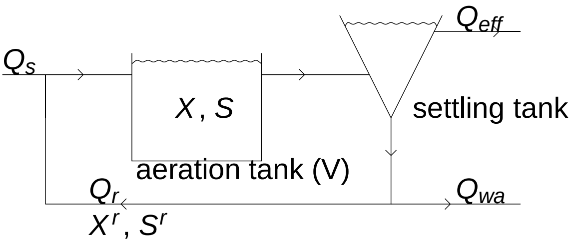
N°	Position	Name	Measure type
11	Before biology 2	*H*	Height of wastewater before the overflow
12 13 14 15	In biology 2	*O*21 *MES*21 *O*22 *MES*22	Dissolved oxygen Suspended matter Dissolved oxygen Suspended matter
16 17 18	After biology 2	*NH*2 *NO*2 *OP*2	Ammonium Nitrate Orthophosphate

Biological mechanisms → ASM1 (Activited Sludge Model)



X, concentration of particle
S, concentration of substrate
Q, flow

Biological mechanisms → ASM1 (Activited Sludge Model)



- Mass balance equations :

$$\dot{\xi}^a_\alpha = D_s \xi^{in}_\alpha + D_r \xi^r_\alpha - (D_s + D_r)\, \xi^a_\alpha + \mathscr{R}_\alpha, \qquad D_s = \frac{Q_s}{V}, \quad D_r = \frac{Q_r}{V}$$

$\mathscr{R}_\alpha$ degradation of the compound α

$\xi^{in}_\alpha, \xi^r_\alpha, \xi^a_\alpha$ concentration of α(input, recycling, aeration tank)

$\xi = [S_I, S_S, S_{NO}, S_{NH}, S_{ND}, S_{O_2}, X_I, X_S, X_H, X_A, X_{ND}]^T$

Model of knowledge

Model reduction for taking into account only the measured variables

- Absence of anoxic growth
- Simplification of model dynamic
- Simplification of the organic compounds
- Simplification of the nitrogenized compounds

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Reduced model

depends only on nine variables :
D_S, X^{in}_{COD}, X_{COD}, S^{in}_{NO}, S_{NO}, S^{in}_{NH}, S_{NH}, S_{O_2} and the aerators working

After linearization and discretization (sampling step=1)

$$\begin{cases} X_{COD}(k+1) = D_S X_{COD}^{in}(k) + A_{COD} X_{COD}(k) + B_{NH} S_{NH}(k) + k_1 \\ S_{NO}(k+1) = D_S S_{NO}^{in} + C_{NO} S_{NO}(k) + D_{NH} S_{NH}(k) + k_2 \\ S_{NH}(k+1) = D_S S_{NH}^{in}(k) + E_{NH} S_{NH}(k) + F_{COD} X_{COD}(k) + k_3 \\ S_{O_2}(k+1) = G_{O_2} S_{O_2}(k) + H_{NH} S_{NH}(k) + I_{COD} X_{COD}(k) + k_L a(k) + k_4 \end{cases}$$

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Determination of potential redundancy relations structures

- only for a biology
- for the whole station in the future

Links between variables and available sensors

Variables	Sensors	
	Biology 1	Biology 2
D_S	Q_{in}	Q_{in}
X_{COD}^{in}	A	?
X_{COD}	?	?
S_{NO}^{in}	x	NO1
S_{NO}	NO1	NO2
S_{NH}^{in}	σ	NH1
S_{NH}	NH1	NH2
S_{O_2}	O1	O21 and O22

Black box model

"Static"

- Determination of the relations by multiple linear regression

$$y_i(t) = \sum_{j=1}^{p} \theta_{ij} \, u_j(t)$$

with $y_i(t)$ explained variable, $u_j(t)$ the explanatory variables et θ_j parameters associated with the explanatory variables

- θ_j, optimization of the quadratic criterion $\| \, y_i(t) - \sum_{j=1}^{p} \theta_{ij} \, u_j(t) \, \|_2^2$

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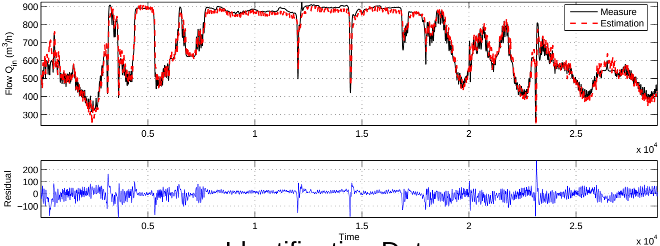
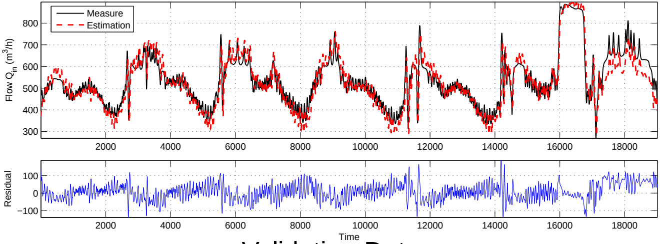
"Dynamic"

- Improvement by adding temporal lag $y_i(t) = \sum_{j=1}^{p} \theta_{ij}\, u_j(t - \tau_j)$

Example : Flow Estimation



Identification Data



Validation Data

Localization of sensor faults

- incidence matrix : relationship between sensors and residuals
- Structural analysis

Localization of sensor faults

- incidence matrix : relationship between sensors and residuals
- Structural analysis

	Q_{in}	T	α	A	O_{21}	O_{22}	...
r_1	1	0	0	0	0	0	...
r_2	0	1	1	0	0	0	...
r_3	0	1	1	1	0	0	
r_4	0	1	1	1	0	0	
r_5	0	0	0	0	0	0	
r_6	0	0	0	0	0	0	
r_7	0	1	0	0	0	0	
r_8	0	1	0	0	0	0	
r_9	0	0	0	0	0	0	
r_{10}	0	1	0	0	0	0	
r_{11}	1	0	0	0	0	0	
r_{12}	0	0	0	0	1	1	
r_{13}	0	0	0	0	0	0	
r_{14}	0	0	0	0	1	1	
r_{15}	0	0	0	0	0	0	

Localization of sensor faults

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	Q_{in}	T	α	A	O_{21}	O_{22}	...
r_1	1	0	0	0	0	0	...
r_2	0	1	1	0	0	0	...
r_3	0	1	1	1	0	0	
r_4	0	1	1	1	0	0	
r_5	0	0	0	0	0	0	
r_6	0	0	0	0	0	0	
r_7	0	1	0	0	0	0	
r_8	0	1	0	0	0	0	
r_9	0	0	0	0	0	0	
r_{10}	0	1	0	0	0	0	
r_{11}	1	0	0	0	0	0	
r_{12}	0	0	0	0	1	1	
r_{13}	0	0	0	0	0	0	
r_{14}	0	0	0	0	1	1	
r_{15}	0	0	0	0	0	0	

- If tests of fault detection of residuals 2, 3, 4, 7, 8, 10 are positive
- Temperature sensor is defect

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r_2	0	1	1	0	0	0	...
r_3	0	1	1	1	0	0	
r_4	0	1	1	1	0	0	
r_5	0	0	0	0	0	0	
r_6	0	0	0	0	0	0	
r_7	0	1	0	0	0	0	
r_8	0	1	0	0	0	0	
r_9	0	0	0	0	0	0	
r_{10}	0	1	0	0	0	0	
r_{11}	1	0	0	0	0	0	
r_{12}	0	0	0	0	1	1	
r_{13}	0	0	0	0	0	0	
r_{14}	0	0	0	0	1	1	
r_{15}	0	0	0	0	0	0	

- If tests of fault detection of residuals 2, 3, 4, 7, 8, 10 are positive
- Temperature sensor is defect

- If tests of fault detection of residuals 12, 14 are positive
- Oxygen21 or Oxygen22 sensor is defect

Conclusion and perspective

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- Determination of potential redundancy relations structures
- Determination of black box-model
- Highlight quasi-direct relations

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Prospects

Improvement of model characterizing the biologies by :

- using Prediction Error Method (ARX, ARMAX, ...)
- adding non-linearity and multi-models
- taking into account boolean signals (pump command)
- PCA modelling
- Confidence interval of the model