Hybrid linear observer for an activated sludge process with alternate phases

Christian Feudjio, Isabelle Queinnec, Alain Vande Wouwer
christiangabin.feudjioletchindjio@umons.ac.be, iqueinnec@laas.fr, alain.vandewouwer@umons.ac.be

UMONS Université de Mons

ICA2017 instrumentation, control & automation

1. Motivations

Alternate phase systems are widely applied to biological wastewater treatment. However the monitoring of these systems is delicate due to the lack of instrumentation and the fact that observability conditions might impair the construction of classical observers. In particular, nor the aerobic neither the anoxic phase taken alone meets the classical observability conditions in the models presented in [1, 2] . To alleviate that issue, we explore the use of a recently proposed hybrid linear observer [3] which is based on a weaker condition: the determinability.

2. Definitions

[3] presents the hybrid linear observer dynamics as:

$$\begin{aligned} \dot{\hat{x}} &= A_q\hat{x}(t) + B_q u(t), \quad t \in [t_{q-1}, t_q], t \neq \hat{t}_k \\ \hat{x}(t_q) &= \hat{x}(t_q^-), \qquad q \geq 1 \\ \hat{x}(\hat{t}_k) &= \hat{x}(\hat{t}_k^-) - \xi_k, \qquad k \geq 1 \end{aligned}$$

$\hat{t}_k = t_q + T_c$: The correction time with $T_c \leq \tau = t_q - t_{q-1}$.
where $x(t) \in \mathbb{R}^n$ is the state, $y(t) \in \mathbb{R}^{d_y}$ the measured output, and $u(t) \in \mathbb{R}^{d_u}$ the input. The switching time $\{t_{q \in \mathbb{N}}\}$ is the time instant where the process moves from one phase to the next.

4. Observer Principle

Assuming both the persistence of the switching and model **determinability** after N switches, [3] introduced a hybrid linear observer based on the idea of **accumulating available information from individual subsystems**.

$N + 1$ Luenberger observers are designed on the observable subspace of each phase. The information provided at the end of the $N + 1$ phases by those observers are then combined at one instance for the computation of the correction vector ξ_k.

For the simulation, S_{O_2} is measured during aerobic phase and S_{NO_3} during the anoxic phase. Based on the determinability analysis, 3 Luenberger observers are required to provide estimates of the estimation error of the observable states in the 3 previous phases:

- $\hat{z}_a = \left[\hat{\tilde{S}}_S, \hat{\tilde{S}}_{NH_4}, \hat{\tilde{S}}_{O_2}\right]^T$ during the aerobic phase.
- $\hat{z}_b = \left[\hat{\tilde{S}}_S, \hat{\tilde{S}}_{NO_3}\right]^T$ during the anoxic phase.

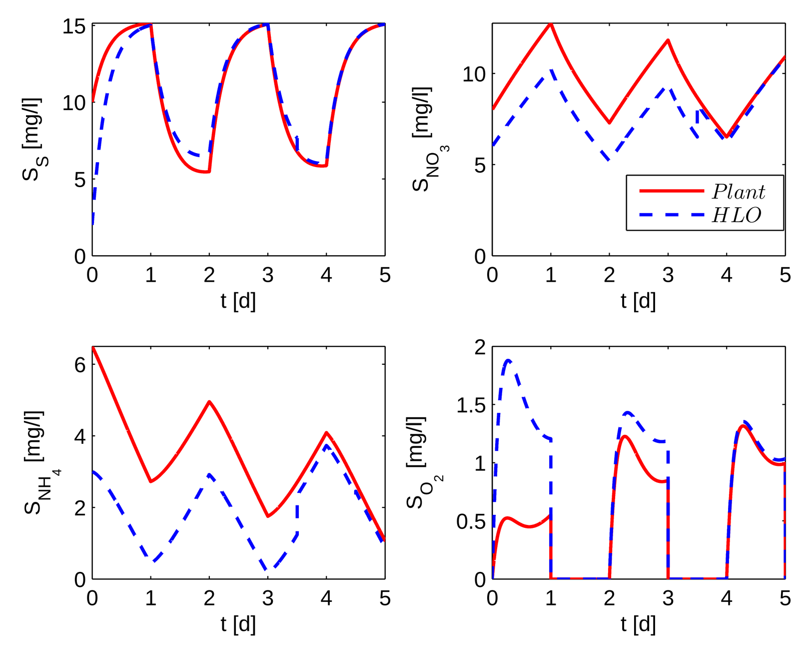
3. Determinability Analysis

Applying the Necessary and Sufficient Condition for assessing a switched system determinability introduced in [3] gives some sensor configurations which allows the observer design.

Measured variables		Determinability	Minimal commutation number
Aerobic Phase	Anoxic Phase		
$[S_{O_2}, S_S]$		×	∞
$[S_{O_2}, S_{NO_3}]$		✓	1
$[S_{O_2}, S_{NH_4}]$		×	∞
$[S_{O_2}]$	$[S_S]$	✓	2
$[S_{O_2}]$	$[S_{NO_3}]$	✓	2
$[S_{O_2}]$	$[S_{NH_4}]$	✓	2
$[S_{NO_3}]$	$[S_{NH_4}]$	×	∞

Table 1. Some determinability analysis of the linear model for two sensors configurations.

5. How does it work?



for $t \in [3\ 4]$

$$\begin{aligned} \dot{x} &= Ax + Bu \\ \dot{\hat{x}} &= A\hat{x} + Bu \\ \hat{x}(\hat{t}_1) &= \hat{x}(\hat{t}_1^-) - \xi_1; \end{aligned}$$

$$\begin{aligned} \hat{t}_1 &= t_3 + T_c \\ &= 3 + 0.5 = 3.5, \\ \xi_1 &= f(\hat{z}_3^-, \hat{z}_2^-, \hat{z}_1^-). \end{aligned}$$

for $t \in [4\ 5]$

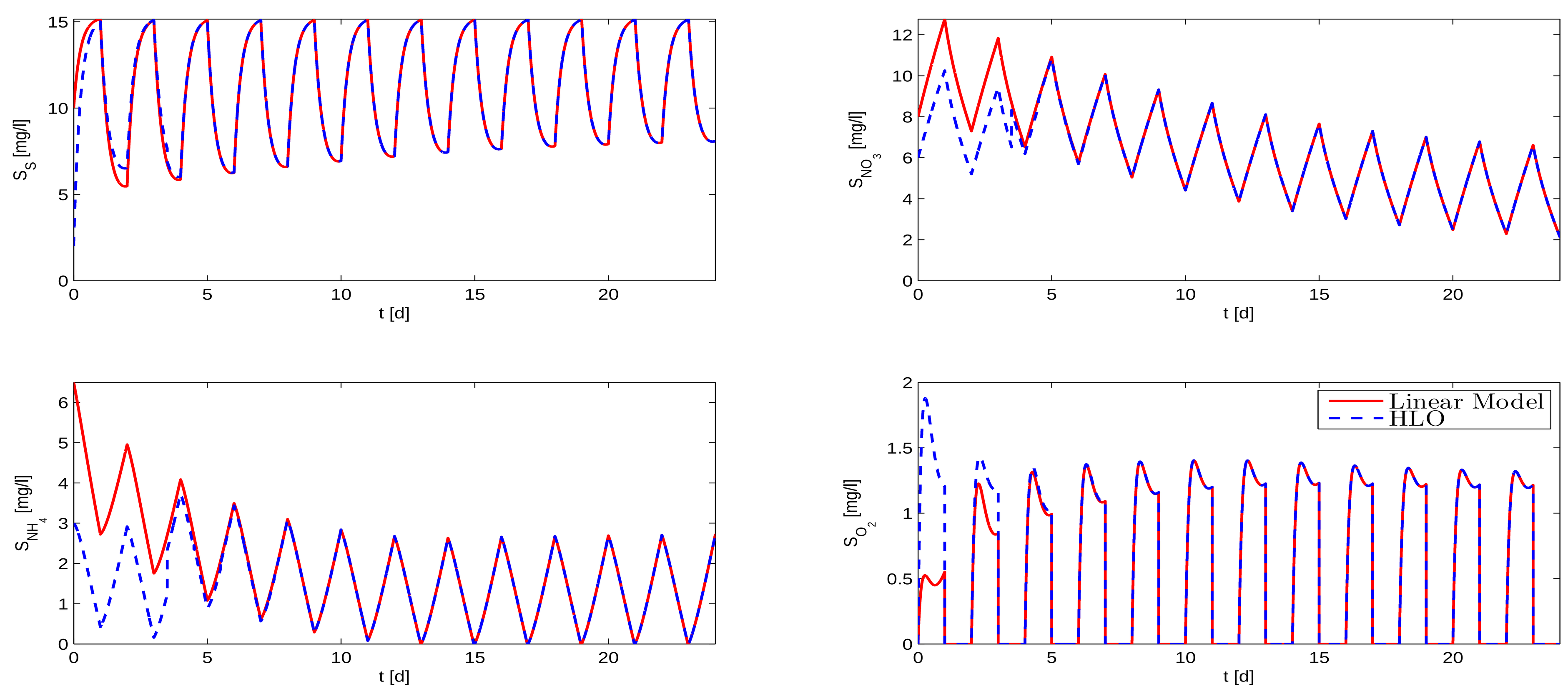
$$\begin{aligned} \dot{x} &= Ax + Bu \\ \dot{\hat{x}} &= A\hat{x} + Bu \\ \hat{x}(\hat{t}_2) &= \hat{x}(\hat{t}_2^-) - \xi_2; \end{aligned}$$

$$\begin{aligned} \hat{t}_2 &= t_4 + T_c \\ &= 4 + 0.5 = 4.5, \\ \xi_2 &= f(\hat{z}_4^-(\xi_1), \hat{z}_3^-, \hat{z}_2^-). \end{aligned}$$

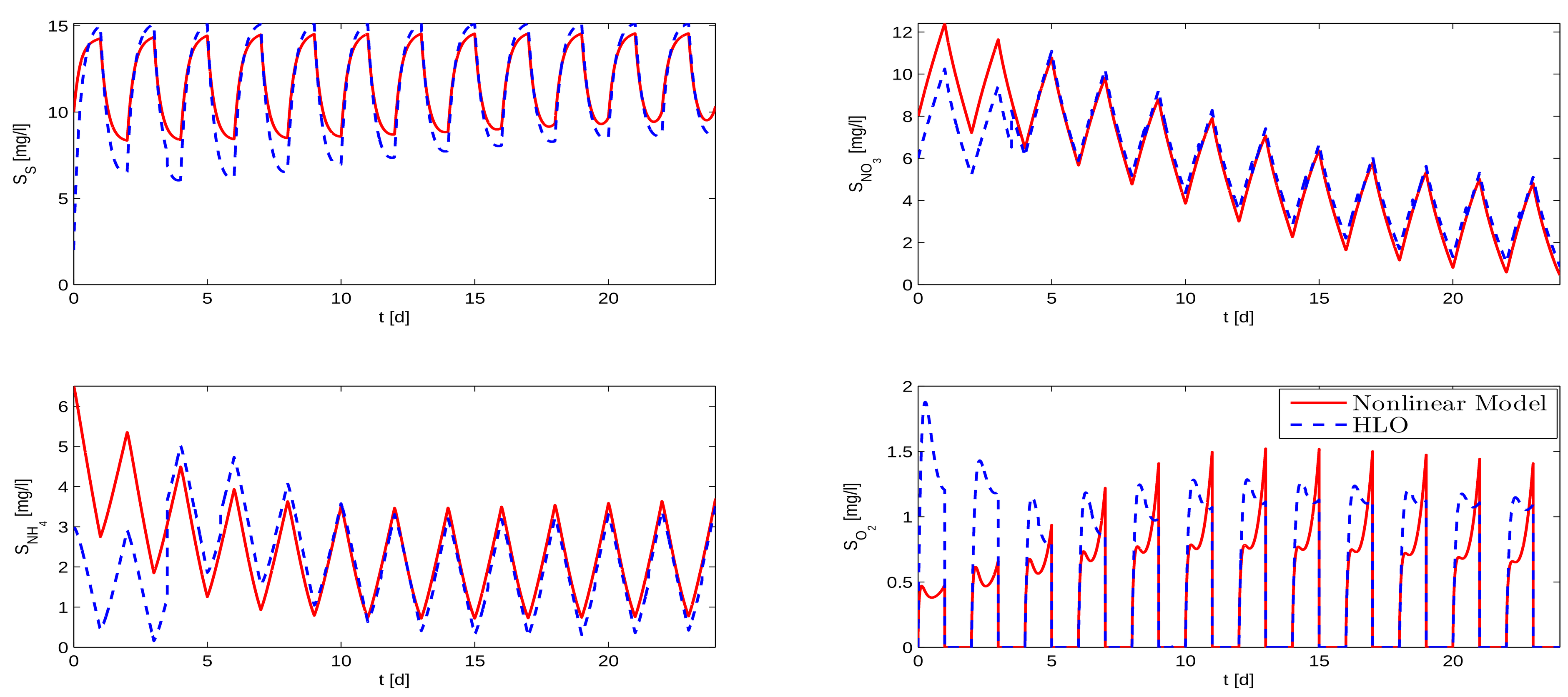
Where $\hat{z}_q^- = \hat{z}(t_q^-)$ is the estimation prior the switching.

6. Simulation Results

The designed HLO estimates perfectly the states while emulated with the linear model [1, 2].



Although the application of the observer to the nonlinear model [1, 2] seems less satisfactory at first sight, the observer is still able to provide good estimates for the states of interest : S_{NH_4} and S_{NO_3}.



References

[1] C.S Gomez-Quintero. (2002). *Modelisation et estimation robuste pour un procede boues activees en alternance de phase*. PhD Thesis. Universite Toulouse III, Laboratoire d'Analyse et d'Architecture des Systemes du CNRS.

[2] C.S Gomez-Quintero, I. Queinnec and J.P. Babary. (2000). *A reduced nonlinear model of an activated sludge process*, In: International Symposium on Advanced Control of Chemical Processes (Adchem). 1037-1042.

[3] A.Tanwani, H. Shim and D. Liberzon. (2013). *Observability for switched linear systems: Characterization and observer design*, IEEE transactions on automatic control, 58(4):891-904.

Acknowledgements

This poster presents research results of the Belgian Network DYSCO (Dynamical Systems, Control, and Optimization), funded by the Interuniversity Attraction Poles Programme initiated by the Belgian Science Policy Office.