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On the Discrete Time Stepwise Safe Switching Soft Sensor Design for Water Distribution Networks

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ABSTRACT

Maintaining an adequate residual chlorine concentration in a WDN is essential, since it provides protection against microbial regrowth and secondary contamination. Because real-time measurement at many internal locations is costly, networks typically rely on sparse sensing, leaving important sections unobserved. This motivates the use of soft sensors to estimate chlorine concentration at unmeasured locations from available measurements.

Toward this goal, the present paper develops a discrete-time, model-based soft sensor for the estimation of residual chlorine concentration in selected points of a benchmark WDN with star-like geometry. The network is first described through a nonlinear ordinary differential equation (ODE) system. For the purposes of chlorine estimation, the hydraulic subsystem is approximated in static form, driving the chlorine transport-reaction dynamics. The resulting nonlinear model is linearized around a set of operating points, yielding local linear approximants while exact discrete-time state-space representations are then derived. The proposed soft sensor is developed in the form of a bank of full-order Luenberger-type discrete-time observers, each associated with one of the preselected operating points. The observer gains are selected through a multicriteria design procedure that combines discrete-time pole-location requirements with a norm-based minimization objective. This design approach permits simultaneous shaping of convergence dynamics and attenuation of undesirable transient phenomena in the estimation error. Toward observer parameter selection, considering the nonlinear nature of the optimization process, a numerical strategy is employed. In parallel, an operating-area characterization approach is introduced so that each observer is associated with a region in the operating space where satisfactory estimation performance is guaranteed.

Simulation results on the benchmark network demonstrate that the proposed approach achieves high-fidelity reconstruction of non-measured chlorine concentrations. The estimated trajectories remain very close to the corresponding nonlinear reference responses, while noticeable discrepancies are confined to short intervals during operating transitions.

Keywords— WDNs, Discrete-time soft sensor, Observer bank, Multi-objective tuning, Metaheuristic optimization

REFERENCES

- [1] World Health Organization, *Guidelines for Drinking-water Quality: Fourth Edition Incorporating the First Addendum*. Geneva, Switzerland: World Health Organization, 2017.
- [2] N. D. Kouvakas, F. N. Koumboulis, M. P. Tzamtzi and D. G. Fragkoulis, "Toward the Design of Chlorine Soft Sensors via Stepwise Safe Switching Observers for a Primary Water Distribution Network", in *Proc. 2nd Olympiad in Engineering Science (OES 2025)*, Stavanger, Norway, June 10–14, 2025.
- [3] K. Ogata, *Discrete-Time Control Systems*, 2nd ed. Englewood Cliffs, NJ, USA: Prentice Hall, 1995.
- [4] K. Zhou, J. C. Doyle, and K. Glover, *Robust and Optimal Control*. Upper Saddle River, NJ, USA: Prentice Hall, 1996.
- [5] F. N. Koumboulis, D. G. Fragkoulis, N. D. Kouvakas, and A. Feidopiasti, "Soft sensor design via switching observers," *Sensors*, vol. 23, no. 4, Art. no. 2114, 2023.

Composite water quality indices for supply networks

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ABSTRACT

The quality of water for human consumption is critical for public health and reliability of water services. In water distribution networks (WDNs), quality is a multi-parametric function with spatiotemporal variations. In this context, a comprehensive framework for the assessment and operational monitoring of water quality in WDNs is proposed, based on real-time measurements. The paper summarizes the compliance requirements, based on European and international regulations and guidelines, for the most critical quality indices. Moreover, it contributes towards providing an objective understanding of the quantitative assessment of water quality with the use of composite quality indices, which can support both compliance and operational surveillance by combining multiple parameters into an overall concise assessment. Composite quality indices are classified based on the purpose they serve and their mathematical formulation. Moreover, their suitability for WDNs is discussed based on WDNs' spatial heterogeneity, temporal dynamics, and network operation.

The proposed framework is based on data derived by the SCADA systems, used for supervision and control of water supply networks, and is applied to indicative cases in the water supply network of Lamia, Greece. Indicative composite quality indices, being applicable in real time data of water stations of Lamia have been suggested, based on real-time measurements of quality variables, such as residual chlorine concentration, pH, conductivity, water turbidity, and nitrate concentration. The indices incorporate appropriate threshold values and desired ranges for these quality variables, determined by corresponding regulations and guidelines. The mathematical formulation and the weighting factors of the composite indices are selected to emphasize on parameters of health importance and parameters for early warning of adverse events, while at the same time avoid distortion due to parameters that vary strongly but have little operational value. Real time monitoring of the proposed composite quality indices can be used as a tool for quality assessment and as a basis for early event detection and decision support. The enrichment of composite quality indices with operational parameters of the network such as the age of the water in the network (residence time), measurements of flow, pressure, tank levels or other variables calculated from hydraulic or water quality models, is currently under investigation.

Keywords— Water supply networks, water quality indices, composite quality indices, real-time monitoring, real time quality assessment

REFERENCES

- [1] European Union (2020) *Directive (EU) 2020/2184 of the European Parliament and of the Council of 16 December 2020 on the quality of water intended for human consumption (recast)*. Official Journal of the EU, L 435, pp. 1–62.
- [2] World Health Organization (2022). *Guidelines for drinking-water quality: fourth edition incorporating the first and second addenda*. World Health Organization.
- [3] S. Chidiac, B. Zou, A. Hanna, and R. Jurdi, "A comprehensive review of water quality indices (WQIs): history, models, attempts and perspectives," *Reviews in Environmental Science and Bio/Technology*, 2023
- [4] J. Tomperi, "Assessing water quality in a distribution network based on hydraulic conditions," *Central Asian Journal of Water Research*, vol. 10, no. 1, pp. 40–67, 2024.
- [5] N.D. Kouvakas, F.N. Koumboulis, M.P. Tzamtzi, D.G. Fragkoulis, "Toward the Design of Chlorine Soft Sensors via Stepwise Safe Switching Observers for a Primary Water Distribution Network", 2nd Olympiad in Engineering Science, Stavanger, Norway, 2025.

Toward Edge Implementation of Soft Sensors for Water Distribution Networks

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ABSTRACT

Accurate monitoring of free chlorine residual is essential for the safe operation of water distribution networks, since disinfectant persistence provides a barrier against microbial regrowth and secondary contamination after treatment. In practice, however, chlorine concentration is spatially distributed and time-varying, being affected by hydraulic conditions, residence time, and reactions in the bulk water and at pipe walls. In the present paper it is argued that edge computing is particularly suitable for this task, since it supports low-latency execution, reduced communication load, and continued operation even under intermittent cloud connectivity.

In this context, the paper presents an edge-oriented realization of a chlorine soft sensor for a benchmark water distribution network. The estimation scheme is based on a discrete-time bank of switching observers. Starting from a nonlinear network model, local linear approximants are derived around selected operating points, and exact discrete-time state-space models are obtained under zero-order-hold assumptions. On this basis, a bank of full-order observers is constructed so that different observers can be used in different operating regions, thereby preserving estimation accuracy as network conditions vary. Implementation is carried out on an edge–cloud architecture centred on a Node-RED runtime. At the edge, measurements are acquired from a programmable logic controller through Modbus Transmission Control Protocol, while auxiliary quantities and supervisory commands are exchanged through Message Queuing Telemetry Transport. The observer bank, consisting of four observers, runs continuously in parallel within the same runtime. A cloud-supervised switching mechanism selects the active observer, while a gating mechanism ensures that only the estimate of the selected observer is transmitted upstream. This architecture separates estimation from selection, allowing runtime adaptation without interrupting acquisition or local estimation.

The proposed scheme is validated in a hardware-in-the-loop setup, where a real-time simulator of the hydraulic and chlorine dynamics generates measurement data that are injected into a physical programmable logic controller.

Keywords— Soft Sensors, WDNs, Edge Computing, Switching Observers, Hardware-in-the-Loop Validation

REFERENCES

- [1] E. Q. Shahra, W. Wu, S. Basurra, and A. Aneiba, “Intelligent Edge-Cloud Framework for Water Quality Monitoring in Water Distribution System,” *Water*, vol. 16, no. 2, Art. no. 196, 2024.
- [2] A. Pagano, D. Garlisi, I. Tinnirello, F. Giuliano, G. Garbo, M. Falco, and F. Cuomo, “A survey on massive IoT for water distribution systems: Challenges, simulation tools, and guidelines for large-scale deployment,” *Ad Hoc Networks*, vol. 168, Art. no. 103714, 2025.
- [3] World Health Organization, *Guidelines for Drinking-water Quality: Fourth Edition Incorporating the First Addendum*. Geneva, Switzerland: World Health Organization, 2017.
- [4] M. Djerioui, M. Bouamar, M. Ladjal, and A. Zerguine, “Chlorine soft sensor based on extreme learning machine for water quality monitoring,” *Arabian J. Sci. Eng.*, vol. 44, no. 3, pp. 2033–2044, 2019.
- [5] N. D. Kouvakas, F. N. Koumboulis, M. P. Tzamtzi and D. G. Fragkoulis, “Toward the Design of Chlorine Soft Sensors via Stepwise Safe Switching Observers for a Primary Water Distribution Network,” in *Proc. 2nd Olympiad in Engineering Science (OES 2025)*, Stavanger, Norway, June 10–14, 2025.

