RESEARCH BRIEF
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Foundational Control Methods For Water Treatment Systems

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Challenge

Water treatment processes are difficult to optimize due to (a) difficulties in predicting abnormal feed water and process conditions, (b) challenges in water quality measurements, and (c) the need to account for equipment and safety constraints as well as contractual obligations. Significant efforts have been made to model water processes based on fundamental process understanding (termed physico-chemical modeling); however, this type of model cannot predict rare events that can cause catastrophic failures. In addition, such models are difficult to maintain, particularly following changes in infrastructure and/or manual operations. To account for this, our project is focused on the development of reliable, empirical models. This type of model gathers data from sensors and equipment in a facility to build and update the model. Through this project, we evaluate the utility of this data-intensive approach and integrate it into a closed-loop control framework for online/real time process optimization with limited to no need for process-specific detail.

Research Approach

This project focuses on developing approaches and methods for online model identification that enable autonomous monitoring, control, and optimization of decentralized, remote, and unstaffed water/wastewater treatment systems. The project is focused on demonstration of the fundamental capacity to perform process optimization with generic, empirical models. Specific tools developed in this project are aimed at (a) robust, real-time denoising of online sensor data, (b) automated model building and updating, and (c) process optimization through model-based control mechanisms. In this project, we used a pilot-scale closed circuit reverse osmosis (CCRO) desalination system as our testbed. In a follow-up project, we will be using a mobile demonstration-scale direct potable reuse (DPR) system (6 processes in series) as our testbed to develop new empirical models.

Impact

Overcoming the barriers of empirical-based modeling will lead to the development of general models that could enable a plug-and-play type of deployment for any water treatment process. Implementation of such generic models will enable far-reaching optimization of water treatment processes, including energy and operational costs.

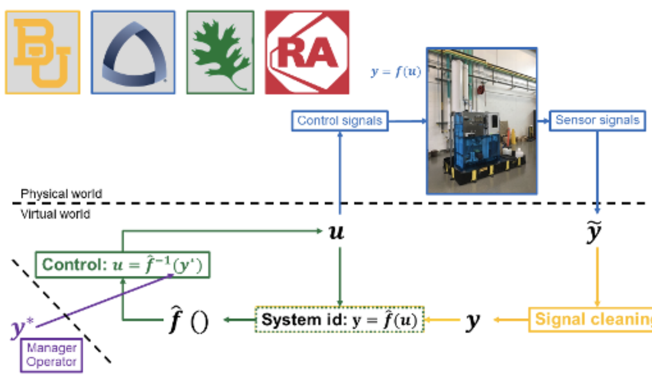

Figure 1. High-level view of data-intensive control architecture based on empirical model building and updating.

Publications and Reports

1. Chowdhury, D., Melin, A., Villez, K. (2022). Method for automatic correction of offset drift in online sensors. Celebrating passion for Water, Science and Technology: Festschrift in Honour of Gustaf Olsson, 17-41.
2. Klandermann, M. C., Lee, J., Villez, K., Cath, T., Hering, A. (2023). Adaptive Online Multivariate Signal Extraction with Locally Weighted Robust Polynomial Regression. Data Science in Science, 2(1), 1-15.
3. Kuras, A., Cath, T. Y., Hering, A. S. (accepted). Functional Data Analysis Approach for Detecting Faults in Cyclic Water and Wastewater Treatment Processes. ACS ES&T Water, in press.

RESEARCH PARTNERS

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Accomplishments & Findings

It is widely believed that automation in the water treatment sector lags behind other process industries because the water industry is "conservative" or "slow to innovate." In reality, automation in the water sector can be more challenging. Water treatment involves monitoring a range of chemical constituents at extremely dilute concentration, which presents a signal-to-noise challenge for in-line sensors and instruments. Furthermore, some of the key factors that govern the effectiveness of water treatment are secondary or tertiary chemical variables issues such as zeta potential, or the level of biological activity in a filter media. Combine the large volumes of fluid being processed in a water treatment plant with the often-tight regulatory constraints on water or effluent quality – and the true challenge in implementing effective automation in the water sector becomes clearer.

Our successful year 1 "seedling" project explored the implementation of model predictive control (MPC) methodologies in a single unit process in water treatment (in this case: a CCRO - closed-circuit reverse osmosis - pilot skid at Colorado School of Mines' West3 Center). We subsequently expanded the scope and technical challenge of this project in a larger project (5.08 – Advanced Process Controls – Autonomous Control and Optimization) in which we conducted automation research on a 6-unit direct-to-potable reuse process mounted on a mobile trailer. The trailer and process were designed by Mines researchers and operated at Colorado Springs and Aurora Colorado in 2022 and 2023.

Our study of model predictive control of a CCRO unit process demonstrated that advanced autonomous control of a critical unit process in water treatment is both possible and can lead to improved efficiency and safety. We were able to show that, when faced with an unmeasured change in a fundamental process variable such as the feed salinity, MPC-based automation can adapt automatically to the new condition and find a new optimum in operation, safely and effectively, without manual operator intervention.

Related Accomplishments

Since we began this project in late 2020, the field of automation in the water sector has grown enormously. "Digital twin" is a buzzword that is now applied widely (and liberally) to a wide range of digital representations of physical water assets and systems. While there are several commercial software products now available for autonomous management of water treatment unit processes, the underlying algorithms and process control strategies are proprietary. By continuing our research, we hope to illuminate what's possible, and how it works, in the open literature.

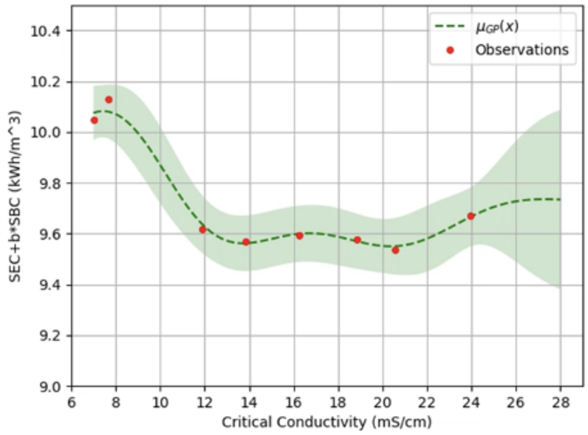

Fig 2. A simple model that correlates performance, a weighted function of the specific energy consumption (SEC) and the specific brine management cost (SBC), to the maximum conductivity value permitted during the filtration phase, which is the main operational parameter in the closed-circuit reverse osmosis (CCRO) process.

Opportunities for Further Research

COVID-19 also greatly accelerated the water industry's interest in, and embrace of, automation and decision support technologies. During the pandemic, operations staff had to rely much more on remote monitoring and supervision. This raised the value of systems that could maintain safe operations with little or no direct operator intervention. As we move to a model of more distributed treatment and water reuse, reliable, effective and open-source autonomous operation tools and methods will be more important.

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