Input design for control relevant modeling of dynamical processes

Aditya Tulsyan, PhD Candidate
Department of Chemical and Materials Engineering
University of Alberta, Edmonton, Canada

Research Goals

The high-performance control systems in bitumen-upgrading units are critical as it allows for: steady and safe operation; consistent product quality; and better energy utilization. Performance of these control systems is critically dependent on the accuracy of the process models. Control engineers would agree that process modeling for effective model predictive control (MPC) is one of their most demanding jobs. Building high-fidelity process model requires novel and innovative methods to design and test dynamic inputs to produce high quality modeling data. Apart from being cost-efficient, a designed input should cause minimal disruption to the normal process operations; reduce energy consumptions and adhere to the strict environmental policies. Under the theme of the industrial input design for maximally efficient crude oil production and proper process utility management through improved control systems, we expect to accomplish the following:

1. Designing dynamic inputs for modeling bitumen-upgrading units such as cokers; distillation columns; and hydro treating units is not easy, considering that the process operates under the following industrial constraints: unavailable measurements of key process variables; inaccurate process knowledge; energy constraints; and environmental regulations. The current design practice is to choose inputs, which satisfies the condition of persistent excitation. These input designs are not only sub-optimal but there is also no guarantee that it would respect the aforementioned constraints. The goal is to develop an efficient optimal input design and test methods for efficient modeling of the bitumen-upgrading units under industry relevant constraints.

2. Given that the model quality degrades as process operations evolve in response to environment and economic demands, as well as change in the geological characteristics of the oil sands deposits, high-fidelity process models must be monitored and updated frequently. This is to ensure that the performance of the control systems stays optimized and the required product quality is maintained. The goal is to develop robust input design strategies that can handle process fluctuations in real-time and also provide an assessment of existing process models.

3. Prior process knowledge plays a critical role in not only designing well-informed inputs but also in high-performance control systems. In addition to prior process knowledge such as constraints, operating conditions, etc., often huge volume of historical process data is also available. Whilst designing inputs for modeling in particular, it is often desirable to include as much relevant information as possible; however, the procedure to organize information for its optimal utilization is area specific and is also a subject of further research. The goal is to develop methods for filtering out irrelevant process information to ensure that the designed inputs are not only optimal but also well informed based on the available process information.

4. Apart from the simulation-based validation of targeted goals, we plan to do an extensive experimental validation on a pilot-scale distillation column. The goal is to design and test robust input designs for achieving higher product concentration and reduced energy consumption through improved control systems

Methodologies

1. We propose to use a Bayesian framework for integrating prior process information with the design problem. Bayesian methods provide a convenient way to include prior information. Techniques based on Information theory will also be analyzed for systematic organization of the process information.

2. Until now, design problem for dynamical systems assumed a perfect model structure with all states measured. These simplifying assumptions do not reflect reality in total, e.g., in distillation columns wherein measuring product concentrations at each tray is either not feasible or too expensive. We will develop highly effective techniques based on estimation and statistical theories to address some of the constraints.

3. Process fluctuations are characterized by change in process model, parameters or structure. First, we plan to first develop a probabilistic model of the fluctuations followed by its integration with the Bayesian design methods.

4. The industrial type distillation column at the University of Alberta has a series of manipulated variables such as reflux flow; distillate flow; bottom flow; reboiler; and condenser heat duty whereas dependent variables include tray temperatures and product composition. Online measurements for top and bottom product concentrations are not available. Frequent changes in column dynamics with continuous influx of process and thermodynamic fluctuations, makes model building an intricate task. We will test our input design solution on this column, followed by modeling and implementation of optimal control to achieve higher product separation and reduced steam consumption.

Research Impact

By 2015, bitumen production from oil sands in Alberta will contribute 75% of total Canada's crude oil production. Whilst the economic benefits in oil sands research is clear, amidst tighter environmental policies demand for a sustainable development in Alberta's oil sands program through improved process control systems is also on rise. Control systems in oil sand industry serves as an integral part in ensuring that the industry is environmentally responsible and economically viable.

Control systems in extraction and upgrading units operate under challenging circumstances: unavailability of measurements of key process variables and uncertain plant operations. Under such constraints, there is greater requirement for efficient extraction and processing of the information for developing time and cost saving robust input design techniques for control relevant dynamical modeling.

Although we primarily intend to focus on the oil sands operations, other process industries will also immensely benefit from the research. It will provide them with a tool to systematically design cost cutting yet informative inputs for process modeling which finds applications in but not limited to designing control systems; resource management; product and process optimization and much more.