NSERC INDUSTRIAL RESEARCH CHAIR
Control of Oil sands Processes

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IRC Workshop 2019

IRC Research Team

IRC Workshop

2019 IRC Annual Workshop Presentations

Fault-Tolerant Reinforcement Learning for Intelligent Process Control, by Rui Nian

All process equipment has a finite operational life span and will eventually fail. Some failures are difficult to predict and have the potential to cause damage if not proactively managed. Hence, it is advantageous to have a Fault-Tolerant Control System (FTCS) in place to ensure an acceptable level of performance during these failures. This presentation proposed a reinforcement learning based FTCS. The FTCS was simulated on the Wood-Berry distillation tower. Results showed the FTCS' fault-tolerant characteristics, robustness to noise, ability to reject external disturbances while being adaptive.

Prediction of Oil Sands Ore Characteristics Using GPS, by Nabil Magbool Jan

For the mining based oil sands industry, it is desirable to determine the quality of ore delivered to the extraction processes in real-time to make optimal operational decisions such as optimal ore blending to achieve maximal bitumen recovery. Currently, the industry determines the real-time ore characteristics based on the 3D geological block model given the shovel Global Positioning System (GPS) information. Typical mining softwares integrate these data from different sources and outputs the ore characteristics. Although it can publish the real-time ore characteristics, this data is not sufficiently accurate due to inaccuracies in modeling the geological data. Therefore, in this work, we present a novel machine learning strategy that utilizes the recently available mining operations data to obtain more reliable ore characteristics given GPS data. Prediction capability of ore characteristics using the proposed modeling strategy has been validated at core hole locations. Further, the prediction of ore characteristics at non-core hole points has also demonstrated promising results.

Distillation Column Flooding Predictive Monitoring, by Lei Fan

Flooding in distillation columns is a major abnormality that can severely reduce the column separation efficiency and the product quality can also suffer. Normally, flooding is observed in two types 1) Jet flooding: excessive vapor flow causing liquid to be entrained and touch the upper trays and 2) downcomer flooding: excessive liquid flows, e.g. feed and reflux flows, fill the downcomer and begin backing up on the tray deck. Regardless of the cause, flooding is often accompanied by sharp increases or fluctuation of column's differential pressures, differential temperatures, or bottom level. The objective of the presented work is to predict flooding events so corrective actions can be taken to prevent them. In this work, both data-based and knowledge-based approaches are attempted. The data-based hierarchical framework is based on Statistical Process Monitoring methods, while the knowledge-based approach calculates the excessive energy into the column, which causes the jet flooding, to predict the flooding events with a pre-warning time slot.

2019 IRC Annual Workshop Presentations

Monitoring analytics in big data KnowledgeNet (KNet) platform, by Mengqi Fang

The KnowledgeNet (KNet) platform is an efficient tool developed by the Integration Object company for the industrial big data analysis. The complete KNet platform is composed of both offline and online KNet related software, namely, KNet Analytics and KNet Online, respectively. For the offline industrial data analysis, KNet Analytics offers a lot of features ranging from basic data pre-processing to advanced data analytic tools, including machine learning, pattern recognition, various regression and optimization techniques, etc. Different offline data analysis approaches can be integrated in a systematic way through the embedded workflow module, and the knowledge explored from offline data analytics can be compiled as a library which can be accepted in KNet Online environment for online usage. Out of these independent features, two integrated toolboxes, i.e., Alarm & Events and Statistical Process Control toolboxes, can be employed to fulfil the purpose of alarm management, fault detection and diagnosis, etc. KNet Online offers an environment for the industry to perform online data analysis. It is composed by KRules, KRCA, KWorkflow, and KMap modules, which work together to monitor the operating status of a process in real time, conduct root cause analysis and send reports to the operators. The most attractive feature of KNet Online is that it supports the MATLAB compiled library. Such feature acts as a bridge between academic research outcomes and industrial applications. Therefore, advanced process monitoring techniques can be implemented on the KNet Online platform. As an example, a demo of electrical submersible pump monitoring running in KNet Online has been presented to demonstrate how the real-time system evaluation is achieved on the KNet desktop.

Tutorial of Reinforcement Learning for Process Control Applications, by Kirubakaran Velswamy

Reinforcement learning schemes provide a viable control platform for interaction driven approaches. Such schemes are based on qualitative feedback obtained from the interaction with the process to be controlled. A higher dimensional, continuous space control problem imparts instability in convergence of the policy/controller to a local optimum. Actor- Critic schemes have proven to improve convergence even in noisy output feedback measurement based systems. The presentation was aimed at reporting a nonlinear multi input-multi output (MIMO) benchmark process' control using the said scheme. With a reward/ penalty based qualitative feedback mechanism, a convolutional neural network based Actor uses learnt in an unsupervised manner to control the levels in the said synthetic model. Hence, a control oriented, approach to reinforcement learning for chemical engineering type systems was presented and discussed.

Introduction to Deep Learning, by Hareem Shafi

With the availability of higher computational power and large amounts of data, deep learning has demonstrated accuracy benchmarks and is being applied to increasingly new areas. This presentation explores deep learning methods as data driven machine learning methods that have the capability of extracting representations needed for feature detection or classification from raw data. The concepts behind deep learning are introduced. The presentation then goes on to elaborate by means of examples how deep learning methods are employed to formulate and solve supervised and unsupervised learning problems as well as its role in reinforcement learning. It concludes by outlining possible industrial applications.

Introduction to cybersecurity of industrial control systems (ICS), by Genghong Lu

An overview of Industrial Control Systems (ICS) and typical system components is presented from an international standard (IEC 62264-1) point of view. Many differences between Operational Technology (OT), Cybersecurity, and IT Cybersecurity, such as availability requirements, security consequences and resource requirements, stem from the fact that logic executing in ICS has a direct effect on the physical world. By far, some countermeasures have been proposed to protect control systems, including international standards (IEC 62443, NIST SP 800-82) and attack detection methods. Situation Awareness (SA) is an efficient tool to detect attacks when the adversary injects false data to compromise the integrity of process information. There are various attack signals for the adversary to achieve different goals. For example, in a square-wave attack, the frequency and multitude of attack signals can be changed frequently to cause fatigue to the control devices. This presentation overviewed international standards, provided examples of adversary attacks, and discussed some of the existing solutions to detect the attacks and protect control systems.

2019 IRC Annual Workshop Presentations

Tutorial on Causality Analysis Toolbox, by Aswathi Prabhakaran

Causality analysis has found applications in numerous fields like science, engineering, and economics. For instance, in process industry, causality helps in finding the root cause of oscillations in process variables, causality helps crude oil price analysts to differentiate the price of setter crudes from the crudes which follow the general market trend. Thus causality analysis deals with problems like identifying the root cause of a particular incident, an abnormality, a particular market trend or in general, the cause of a particular event. The causality toolbox developed by the IRC group can BE used to identify causal relationships between different process variables. Depending on the nature of process variables (Gaussian or non-Gaussian), causal relations (linear or nonlinear) and domain of analysis (time or frequency), different methods are used. Some causal analysis methods require model to be identified first, whereas some methods are model free i.e. the causal relations are derived directly from the data. The toolbox demonstrations on a simulation dataset showed promising results and the causal relations between the variables were identified with acceptable accuracy.

Image Processing Techniques Relevant to IRC Work, by Oguzhan Dogru

Basics of image processing, representation, and manipulation were presented alongside with areas of application such as detection and tracking of interfaces through sight glasses of a Primary Separation Vessel, where a successfully developed case by our group is also presented. Extension of this work is planned to tackle other challenging situations such as a corrupted interface image with noise and unusual lighting conditions. Enhanced image processing techniques based on machine learning are also on the perspective.

Overview of SAGD Projects in Progress and Future Research, by Rahul Raveendran

Under this IRC program, we have had the opportunity to pursue several research projects to improve the current state of SAGD operations. We can broadly categorize these research projects into the following three categories, 1) soft-sensing, 2) monitoring and 3) optimization. Soft sensing projects include the development of predictive models for difficult to measure key quality variables in the SAGD facilities. Monitoring projects include health monitoring of process equipment and monitoring of process operations for safety and abnormal condition detection. Optimization projects include those that specifically aim for economic and energy optimization of the SAGD facilities. Some of the on-going research projects under each of these banners include:

1) Soft-sensing: (i) emulsion flow soft sensor, (ii) water content soft sensor, and (iii) steam quality soft sensor

2) Monitoring: (i) Fouling buildup monitoring in OTSGs, (ii) Subcool control performance monitoring, (iii) Steam breakthrough monitoring, and (iv) ESP monitoring

3) Optimization: (i) Plant-wide water network optimization, (ii) Heat exchanger network optimization, (iii) Steam allocation optimization, and (iv) Diluent blending optimization.

Tutorial on Soft Sensor Analytics Toolbox, by Arun Senthil

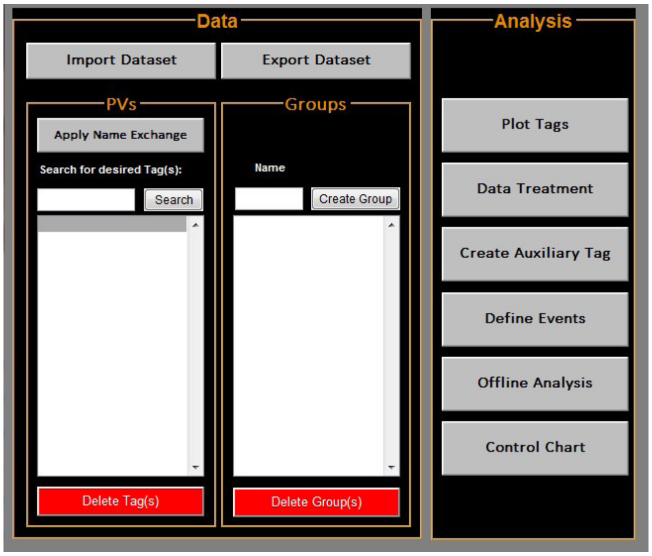
Soft sensors play an important role in oil sands industries. They help in predicting the variables that are hard to measure which can be later used for the purpose of process monitoring and control. In this tutorial, we demonstrate a toolbox that has been developed in our group. Such toolbox provides a unified platform for efficient soft sensors design that is not limited to data driven models, but also enable users to include process knowledge through first principles equations. The toolbox was demonstrated using 2 case studies, namely, using Near Infra-Red (NIR) data and Sulphur recovery unit data.

NIR Applications in Oil Sands, by Alireza Kheradmand

Near InfraRed (NIR) spectroscopy plays an important role in identifying material components. It is widely used in oil industry for different purposes. In this project, NIR is used to analyze samples taken from different locations of an oil sands tailing pond to obtain their solid and water contents. The samples are taken from different depths and locations. Coagulants were added to the samples, to facilitate the settling process in Mature Fine Tailing (MFT). Coagulant is injected at different dosages labeled as “low”, “medium”, and “high”. Initially, a soft sensor is built to predict a number of target properties such as water and solid content and their relative properties online. In addition, coagulant consumption in water treatment section needs to be monitored for economical purposes. Using machine learning techniques including wavelength selection, dimension reduction and locally weighted modeling, a set of locally weighted predictive classification models have been built to predict dosage of coagulant injected to each individual sample. Both predictive model structures demonstrate reasonable performance, and they are being validated for future implementation.

Laboratory and Toolbox

Predictive Monitoring Analytics Toolbox, by Fadi Ibrahim, et al. Gas Flare events prediction is used as a case study to demonstrate an updated front-end design of the Predictive Monitoring Analytics Toolbox. Such toolbox is designed with the purpose of general failures' prediction applications that are of a high interest for the industry. Failure prediction helps in reducing process downtime caused by failed machines, and helps in reinforcing safety measures and minimizing the harmful impact on the environment. The toolbox runs several Statistical Process Monitoring methods using both time-domain and frequency domain analysis developed by the IRC research team for best performance. It enables the user to perform distributed monitoring on tailored grouping of PVs (ex. process units) and integrate them at a hierarchical layer to obtain one control chart for the whole process/plant. The presented demo & results demonstrated the conviviality of the updated front-end design that eliminated redundancy, centralized grouping & tags manipulations, simplified sub-windows, and enabled the users to switch and/or execute several tasks in parallel with simultaneous flow of information between sub-windows.



IRC Process System and Control Laboratory Updates

Recently, our IRC laboratory has been equipped with a dual GPU deep learning rig from Lambda Labs. This machine is equipped with state-of-the-art hardware, starting with an Intel i9-9820X processor boasting 20 cores. Individual clock speeds can surpass over 4.2 GHz! Next, it comes with 64 GB of the latest DDR4 2666 MHz RAM from Crucial. Intensive computations are no longer an issue because this machine is also equipped with two GIGABYTE nVidia RTX 2080 Tis, connected through an EVGA NVLink system. The machine is fed through a 1300W gold certified EVGA power supply. Additionally, the computer has two easily removable ADATA 2TB SSDs equipped with Ubuntu 18.04 and Windows 10 operating systems. And just in case that was not enough storage, another 4TB hard drive is also installed, and can be accessed through both Ubuntu 18.04 and Windows 10. Preliminary studies have shown that this machine can train a 3 layer neural network 47 times faster than a computer equipped with an Intel i7-6700. The best part, the 2nd GPU was barely even used in this test. With this machine, our IRC lab looks to venture into more computationally intensive fields of research such as computer vision and deep reinforcement learning.

Data Analytics and Machine Learning - Recent IRC Research Initiatives

Reinforcement Learning based Controller for Setpoint Tracking Control of Non-Linear Processes

Model-based controllers have conventionally been used for the control of non-linear processes. They require knowledge of the mathematical model of the system to derive their parameters. The mathematical model might not be readily available or entirely accurate. Additionally, shifts in operating conditions reduce their effectiveness. Lately, reinforcement learning (RL) has emerged as a powerful tool for goal based learning. It has dominated accuracy benchmarks for tasks such as Atari games. It makes sense then to propose a RL based controller as a general purpose controller. They learn directly from interaction with the process data and adapt for shifts in the operating conditions. Interaction occurs between an agent and an environment in a RL setup. The agent takes state observations of the environment s_t to take an action a_t. The action taken causes the environment to transition to a new state and emit a reward r_t associated with being in that state s_t. The RL agent takes actions to achieve its goal, that is, maximizing the accumulated rewards. In analogy to process control (Figure 1), the agent corresponds to the controller while the environment corresponds to the process. The reward reflects the cost function provided at every time step to indicate the performance of the agent, setpoint deviation in this case.

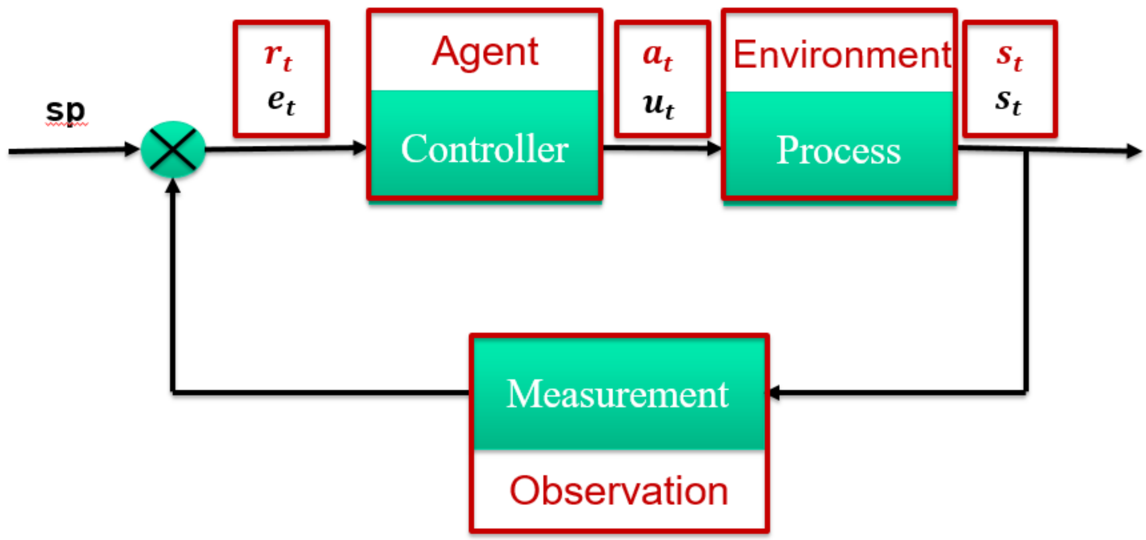


Figure 1: Analogy of Reinforcement Learning to Process Control

The specific RL algorithm we have used in our implementation is the Asynchronous Advantage Actor-Critic (A3C) algorithm. It comes from a class of algorithms known as the Actor-Critic algorithms. In these algorithms, the RL agent consists of an actor, which models the agent's decision making (the policy), and a critic, which determines the long term value of the actions taken by the actor. The A3C has a global copy of the actor and the critic from which it makes multiple local copies. Each of those local copies then runs simulations on the separate fixed-time instantiations of the environment known as episodes. After each episode, the actor and critic are updated to achieve the goal. The use of function approximators for both actor and critic allows for continuous state and action space to be used.

The effectiveness of the proposed RL controller has been demonstrated on a quadruple tank system. The levels of the bottom tanks were to be maintained at particular setpoints by controlling the pump voltages. The RL controller was able to converge to a policy that successfully tracked the setpoint changes in the quadruple tank system. After the success of the RL controller on quadruple tank system, its application is being extended to the Primary Separation Vessel (PSV).

IRC digital Transformation/Database Management System

When managing large volumes of data, it is much easier to do so using database management systems. These systems implement databases which hold vast collections of raw data; a database server contains multiple databases that can be referred to as a space. Subsets of these data can be retrieved using querying languages. Databases support data compression, filtration, projection, and relation depending on the database used. Databases traditionally stored data in the form of tables, however recently some databases support other forms of data, including: graphs, key-value pairs and documents. A database can then be treated as a single source of truth, eliminating redundant copies that are prone to error. With potentially confidential data coming from multiple sources, most databases are equipped with user controls. Users can be assigned with roles, only authorized to run a limited of instructions over specified spaces.

In our lab, we have Cassandra, MySQL, and mongoDB servers set-up. Each of these databases have unique properties suited for different tasks. The experiments in the lab act as data sources. Using the connector program, we are able to connect different experiments with different output formats to supported database servers. Our program currently supports Cassandra, CosmosDB (Azure), MySQL, mongoDB, and SQL server (Azure).

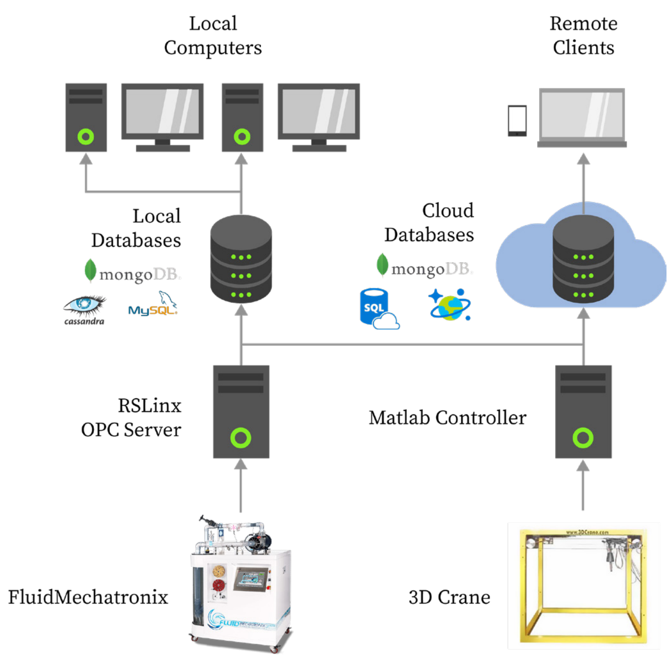


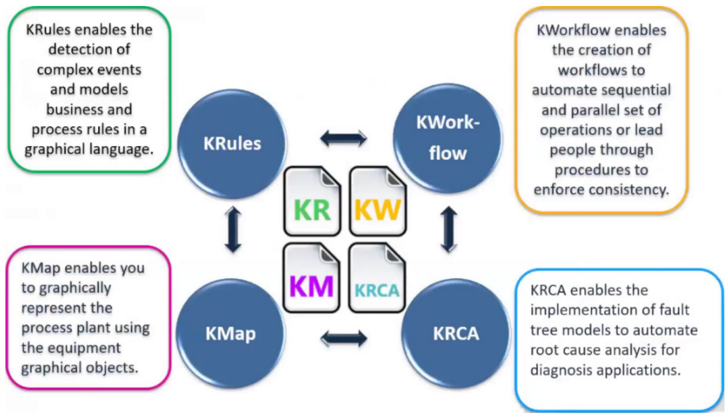
Figure 2: Database pipeline in IRC Lab

We have also developed a retriever program that can be used to retrieve data from database servers. The program was developed to allow users to take advantage of using databases without needing the user to learn any form of querying language. Using the program, users can monitor data using plots and optionally export a subset of the data to a .csv file whenever convenient.

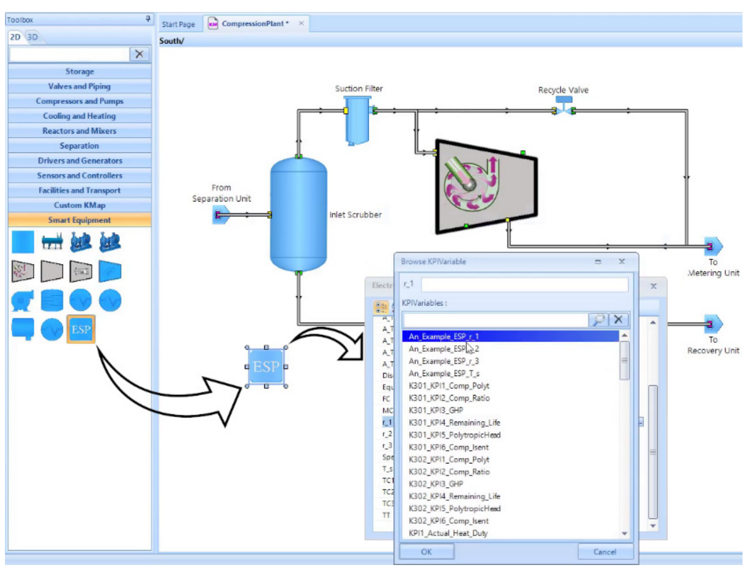
Our aim is to build a central database across the IRC lab. In the future, the uploader program will be distributed to data sources in the lab, allowing data to be pushed to the central database and the retriever program will support multiple plots allowing the program to be used as a dashboard to monitor multiple experiments simultaneously. We also plan to continue our exploration cloud computing to implement a global database.

KnowledgeNet

KnowledgeNet is a software designed to assist in the digital transformation of production facilities to increase their performance, reliability, and safety. It provides Process Engineers with easy-to-use tools for modelling plant activities as well as automating data management, processing, and root cause analysis. Additionally, means of interacting with this information via custom dashboards and real-time data visualizers are included in the suite.



KNet offers scalability by supporting a degree of object-oriented philosophies, in the form of Smart Equipment. These components tie processes together with analysis procedures and human interfaces through a set of Key Performance Indicators, used to monitor the state of the process in an online setting. This enables reuse of the same advanced techniques without recreating each individual part for every object that needs to be modelled – all that is required is routing correct stream of input data to each Smart Equipment.



Modularizing a process that has already been modelled in KNet is quick and easy. As a proof-of-concept, a new piece of Smart Equipment has been developed to combine cutting-edge analysis techniques for ESP seal failure with informative supervisory interfaces in a scalable package. The algorithm has been augmented with some user interfaces and a basic RCA fault tree and, despite some small limitations, simplifies the deployment procedure in projects which are both new and already configured.

Recent publications

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