Soft Sensor Change Point Detection and Root Cause Analysis

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A **soft sensor** is a mathematical model that uses measurable variables $X$ only to estimate the hard-to-measure state variables $Y$.

For industrial soft sensors, getting predictions is not enough. It must also explain why it came to the model output and how to intervene when the model drifts.
Motivation

- How do we know if deployed soft sensor models are still performing well? **Change Point Detection**
- How to interpret the model result? **Shapley value**
- How to find the root cause of the change in soft sensor models? **Shapley value + Causal Discovery**
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Industrial processes are often non-stationary processes with constantly changing working conditions.

Time-series segmentation; Partition into sub-sequences; Boundaries between partitions are change points (CPs).

Change point detection (CPD) identifies structural/abrupt changes within a data sequence.
Research Question 1

If there exists change points in soft sensor predictions, it indicates abrupt and significant changes in the model and may require us to rebuild the model to ensure that it does not drift.

Question 1: How to know if deployed soft sensor models are still performing well? Change point detection
Change Point Detection

\[
\min_{\tau} V(\tau, y) + pen(\tau) := \sum_{k=0}^{K} \sum_{t=t_k}^{t_{k+1}} \| y_t - \bar{y}_{t_k, t_{k+1}} \|^2_2 + \beta |\tau|
\]

- **Input**
- **Possible segmentations** \(\tau\)
- **Change point detection**
- **Output**

**Discrete optimization problem**

**Search method**

**Cost function**

**Penalty**

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The SHAP value is the only machine learning explanation method that guarantees a fair distribution among the features.

- Explain the prediction of any machine learning model.
- Provide local & global explanation.
SHAP values can show how much each feature contributes, either positively or negatively, to the model predictions, including the entire data set (global) and each individual case (local).
Research Question 3

After a change point is detected, it is important to automatically locate the root cause of the change point. Causal discovery aims to infer causal structure from data.

Question 1: How to know if deployed soft sensor models are still performing well? Change point detection

Question 2: How to interpret the model result? SHAP

Question 3: How to find the root causes of the change points in soft sensor models? SHAP + causal discovery
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In this section, a real soft sensor data from Parkland refinery in Burnaby, British Columbia, Canada, is used for case study. 6 months of operational data from an FCC unit, 30 min sampling time, 10 process variables, 1 quality variable, 6586 samples. The objective is to accurately detect the change points and automatically find the root causes of changes.
Change Point Detection

Change point detection result for all features

Change Point Detection: 52_XHCC90
Change Point Detection: 52TI766
Change Point Detection: 52PI250
Change Point Detection: 52FC231
Change Point Detection: 52TI737
Model Explanation

The local and global model explanation for the soft sensor modes

Global explanation: feature importance

Local explanation: feature attribution of all data
Model Explanation

The local explanation and root analysis for change point 1260

Local explanation:
feature attribution of change point 1260

Causal discovery of change point 1260
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• How do we know if deployed soft sensor models are still performing well?
  ✓ Change points of the soft sensors are detected by solving a discrete optimization problem.

• How to interpret the model result?
  ✓ Using SHAP to fairly distribute the contribution of each feature.

• How to find the root cause of the change in soft sensor models?
  ✓ Using causal discovery to find the root cause of change with change point data.

✓ The real-world commercial refinery case study validates the effectiveness of the proposed method.
References

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7. Liang Cao, etc. Stable Learning with Small Samples, will submit.