Real-Time Outlier Detection with Dynamic Process Limits

Process Control 2023

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2023-05-24

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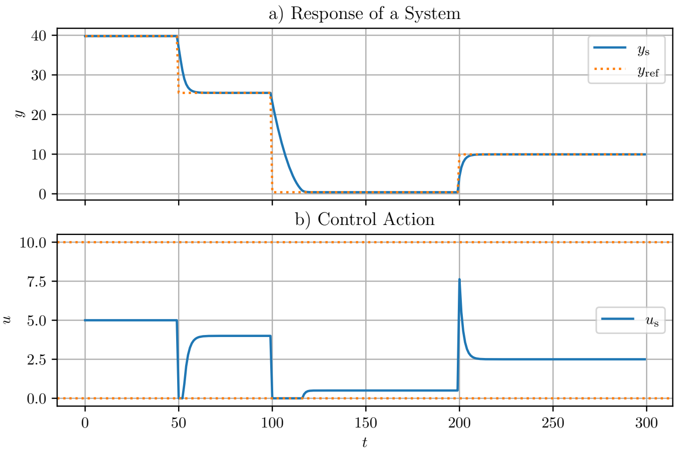
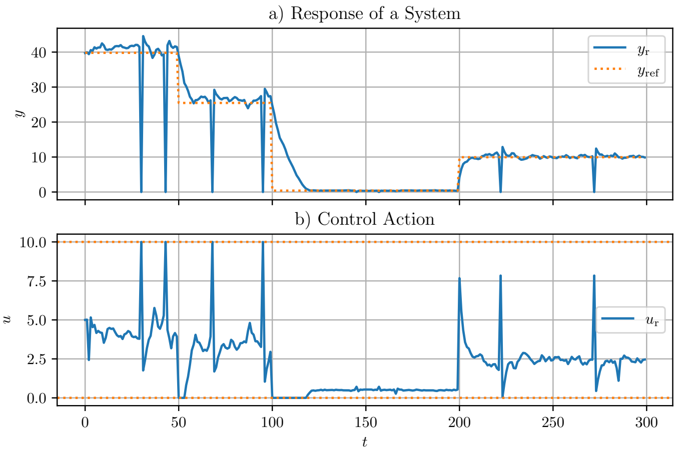
1. Motivation
2. Gaps in Existing Solutions
3. Proposed Approach
4. Results

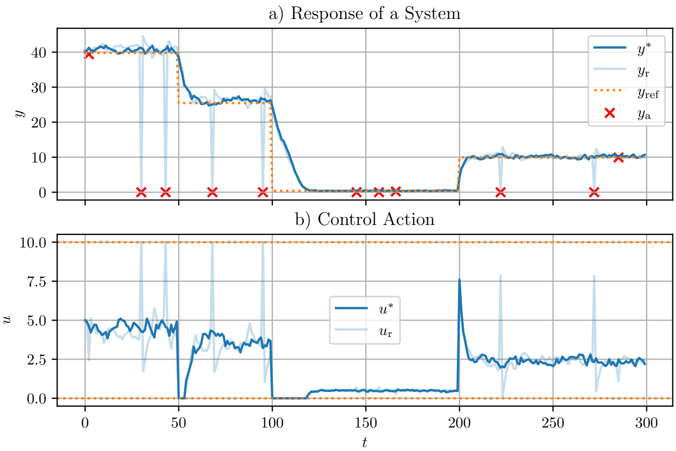
Simulation Results



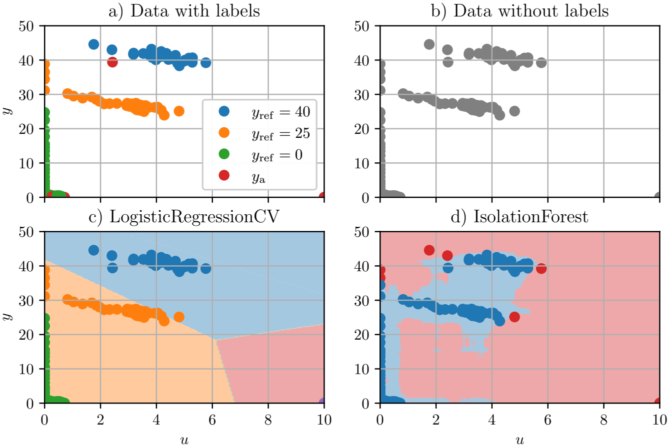
Practical Scenario



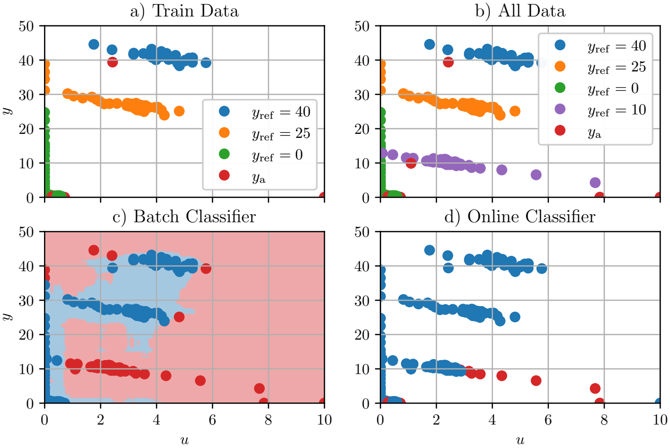
Control Engineering meets Artificial Intelligence



Lack of Labels



Changes in Distribution



Goals

We need to make detector that:

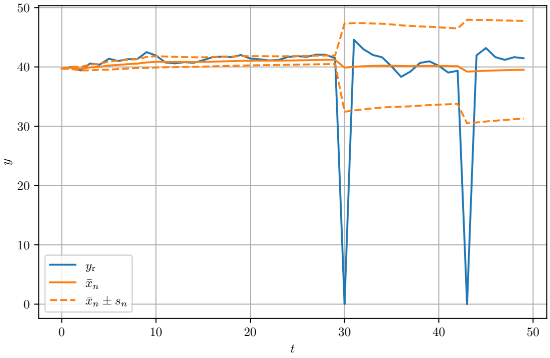
- Does not require huge amount of data
- Adapts to unseen operation
- Offers credible decision boudary
- Does not alter operation of existing systems

Proposed Solution

Real-Time Outlier Detection with Dynamic Process Limits combining:

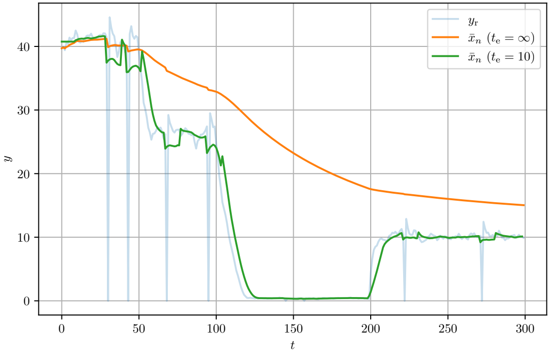
- Online Learning
- Outlier Detection
- Self-supervised Learning
- Soft Real-Time System
- Invertible Probabilistic Model

Welford Algorithm



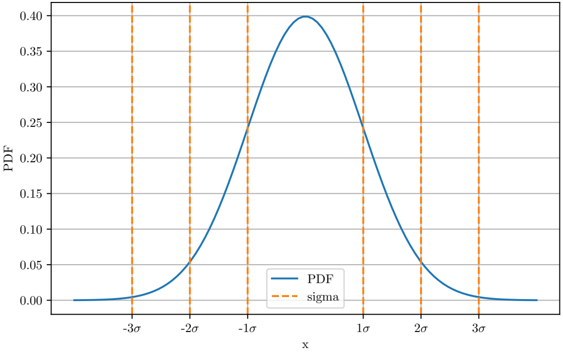
+ One-Pass Algorithm | − Adaptation Slows Down

Inverse Welford Algorithm



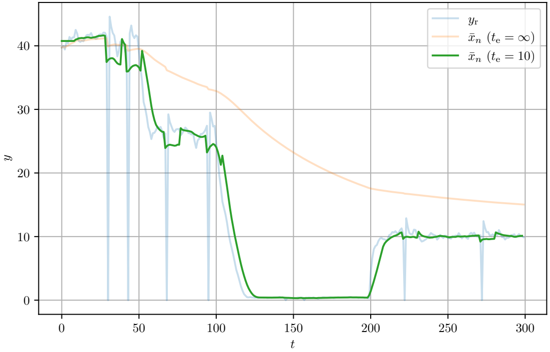
+ Constant Adaptation | − Memorizes Data Window

Distance-based Outlier Detection



$$y_i = \begin{cases} 0 & \text{if } q \leq F_X(x_i; \bar{x}_n, s_n) \quad (1a) \\ 1 & \text{if } q > F_X(x_i; \bar{x}_n, s_n) \quad (1b) \end{cases}$$

Self-Supervised Learning



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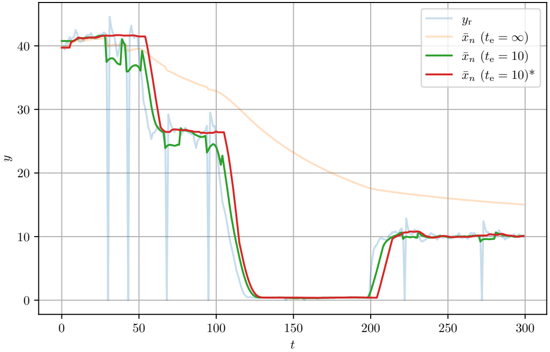
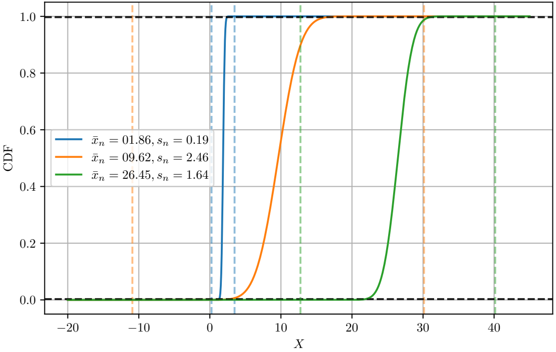
Self-Supervised Learning



$$\frac{\sum_{y \in Y} y}{n(Y)} > q \quad (3)$$

Inversion of CDF



$$x_{\mathrm{l}} = F_X(1 - q; \bar{x}_n, s_n)^{-1}$$

$$x_{\mathrm{u}} = F_X(q; \bar{x}_n, s_n)^{-1}$$

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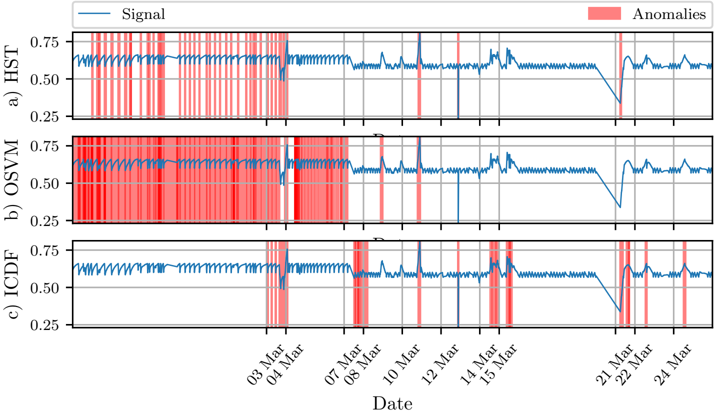
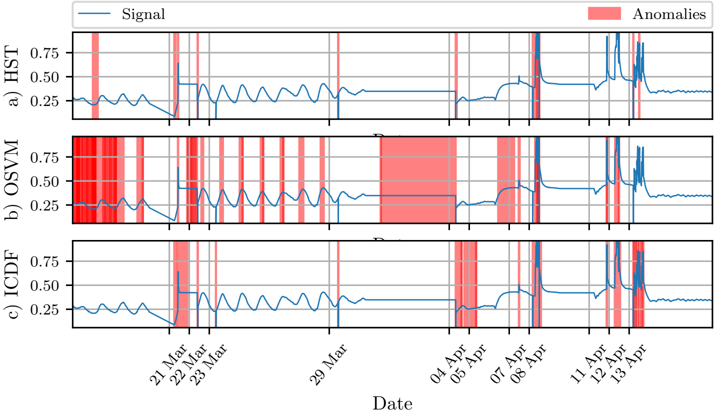
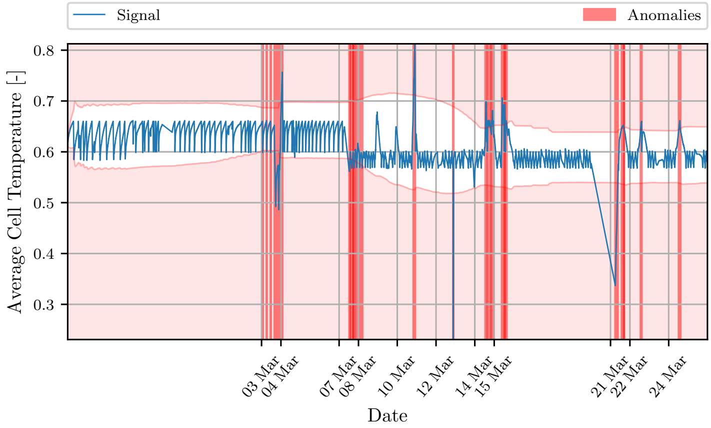
ICDF-based Outlier Detection - BESS



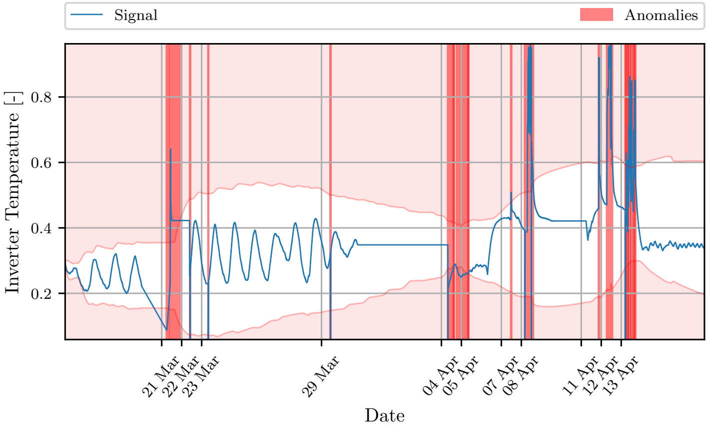
ICDF-based Outlier Detection - Inverter



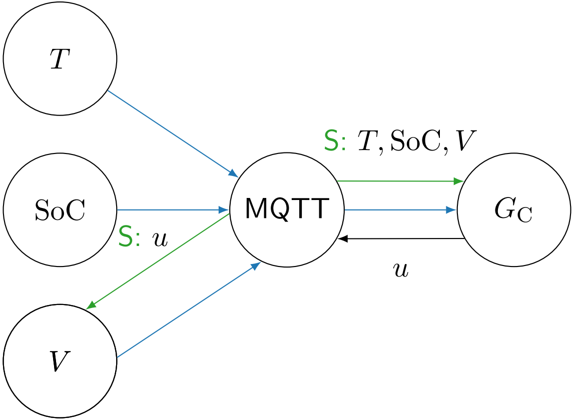
Dynamic Process Limits



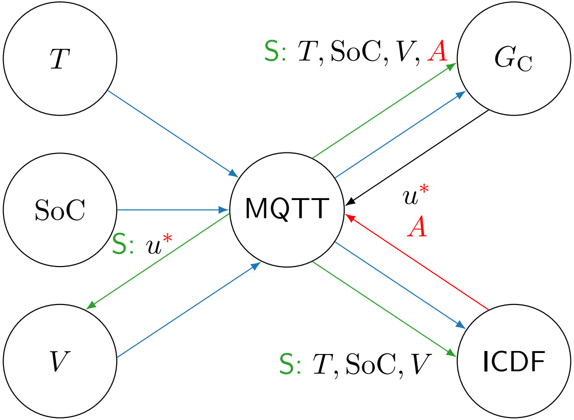
Dynamic Process Limits



Utilize Existing Infrastructure



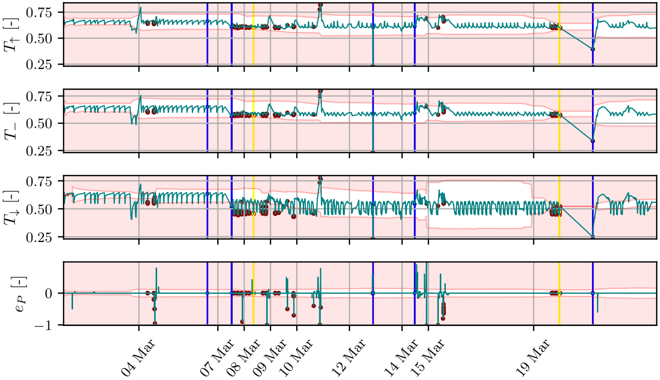
Utilize Existing Infrastructure



Summary

- Automated alerting without prior knowledge of process limits
- Assessment of environmental conditions and device aging
- Self-learning approach using streamed data
- Automated alerting threshold setup for multiple signals
- Seamless integration with existing IT infrastructure

Follow-up research



[1]

[1] M. Wadinger and M. Kvasnica. Adaptable and interpretable framework for novelty detection in real-time iot systems. In Proceedings of the 62nd IEEE CDC, Singapore, 2023. under review.

Online Anomaly Detection Workflow

Input: expiration period t_e, time constant t_c
Output: score y_i, threshold $x_{\mathrm{q},i}$

Initialisation :
$i \leftarrow 1;\ n \leftarrow 1;\ q \leftarrow 0.9973;\ \bar{x} \leftarrow x_0;\ s^2 \leftarrow 1;$
compute $F_X(x_0)$;
LOOP Process
loop
    $x_i \leftarrow$ RECEIVE();
    $y_i \leftarrow$ PREDICT(x_i) ;
    $x_{\mathrm{q},i} \leftarrow$ GET($q, \bar{x}, s^2$);
    if (1a) **or** (3) **then**
        $\bar{x},\ s^2 \leftarrow$ UPDATE($x_i, \bar{x}, s^2, n$);
        $n \leftarrow n + 1;$
        for x_{i-t_e} **do**
            $\bar{x},\ s^2 \leftarrow$ REVERT($x_{i-t_\mathrm{e}}, \bar{x}, s^2, n$);
            $n \leftarrow n - 1;$
        end for
    end if
    $i \leftarrow i + 1;$
end loop