Real-Time Outlier Detection with Dynamic Process Limits

Process Control 2023

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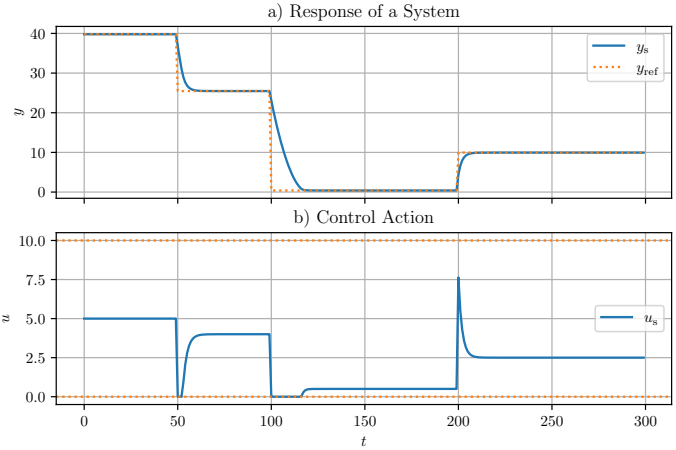
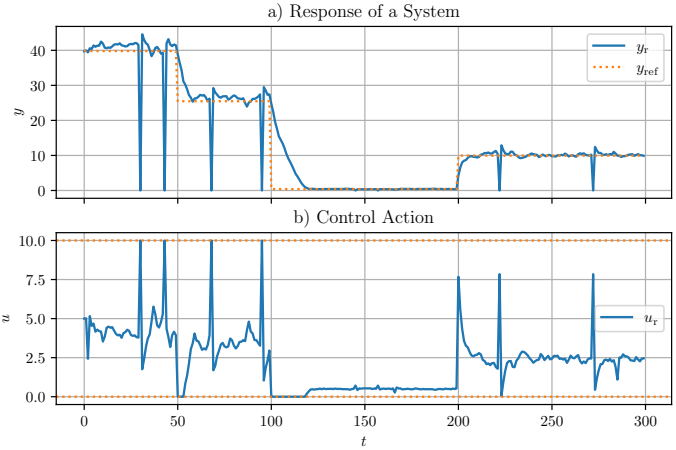
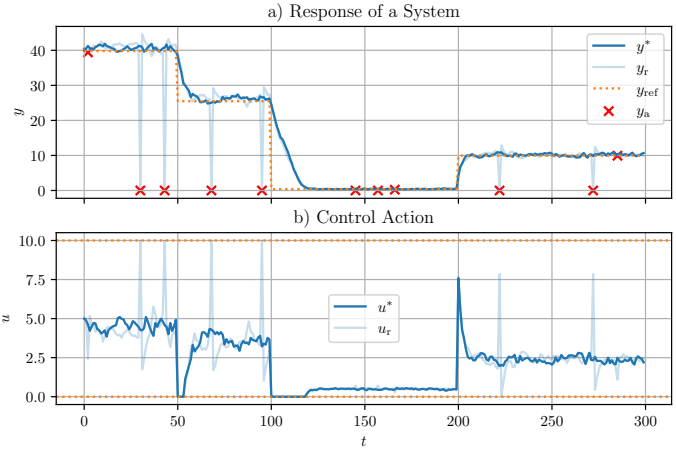
Simulation Results



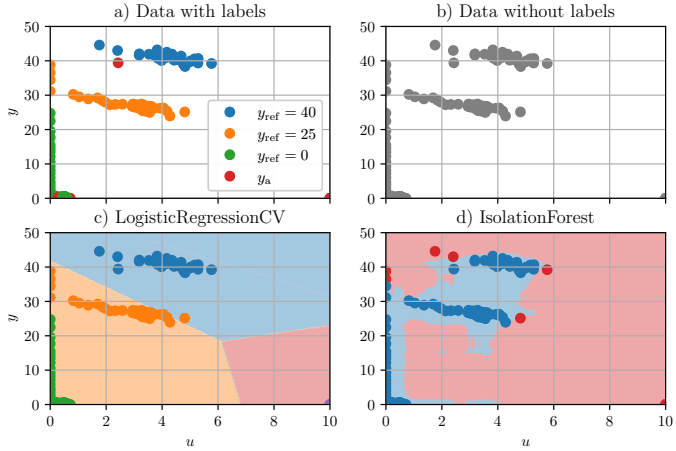
Practical Scenario



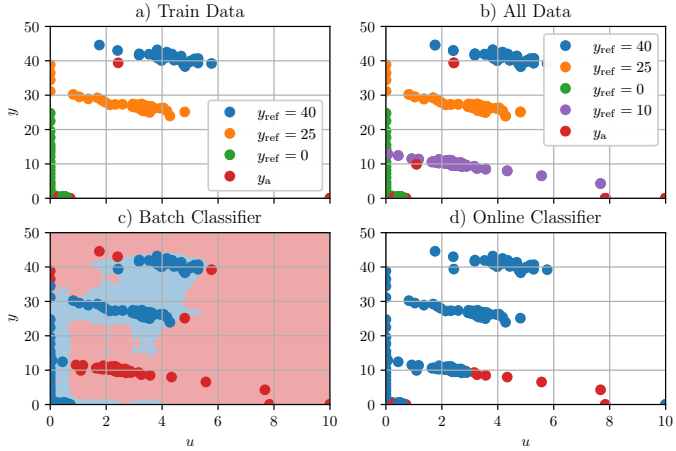
Control Engineering Meets Artificial Intelligence



Lack of Labels



Changes in Distribution



Goals

We need to make detector that:

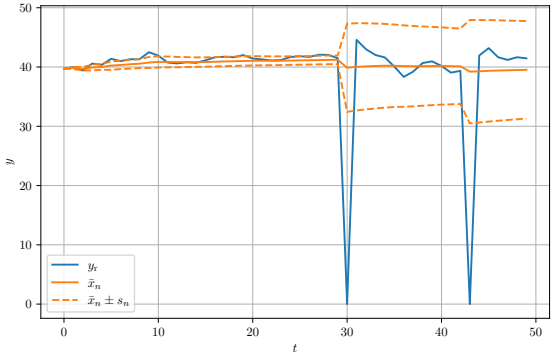
- does not require huge amount of data
- adapts to unseen operation
- offers credible decision boundary
- does not alter operation of existing systems

Proposed Solution

Real-Time Outlier Detection with Dynamic Process Limits combining:

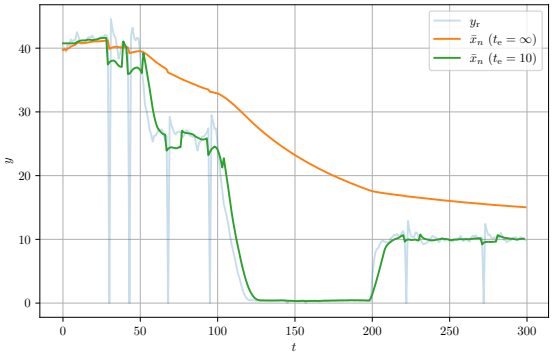
- online Learning
- outlier Detection
- self-supervised Learning
- soft Real-Time System
- invertible Probabilistic Model

Welford Algorithm



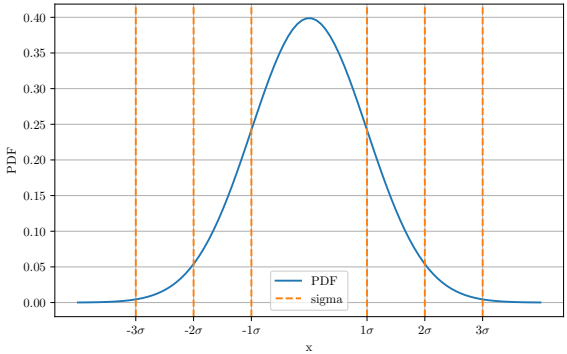
\+ One-Pass Algorithm | − Adaptation Slows Down

Inverse Welford Algorithm



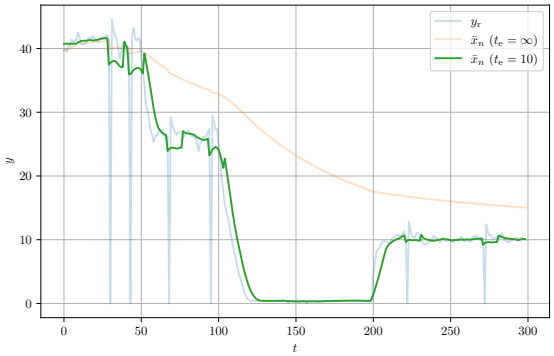
\+ Constant Adaptation | − Memorizes Data Window

Distance-based Outlier Detection



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

Self-Supervised Learning



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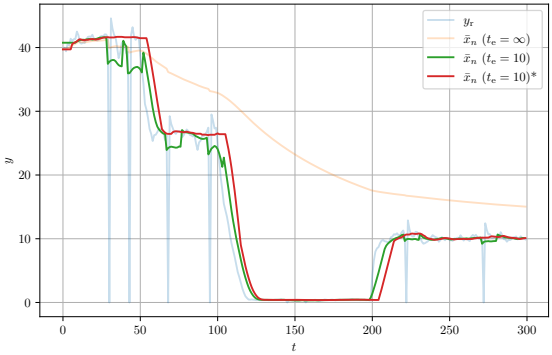
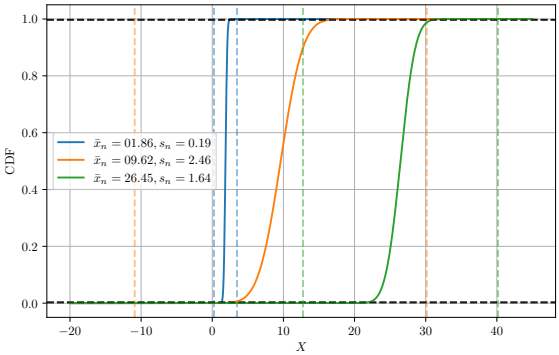
Self-Supervised Learning



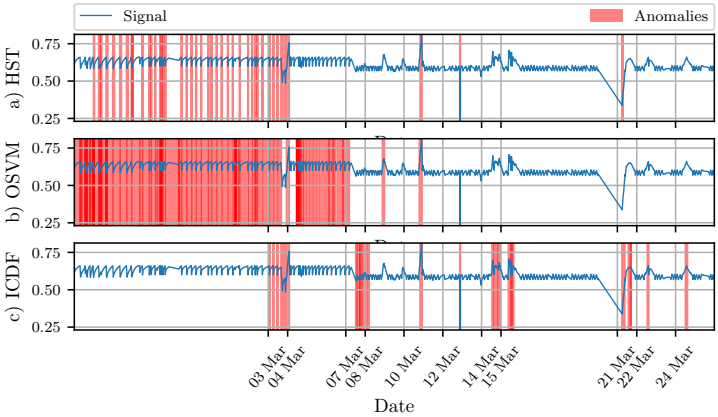
$$\frac{\sum_{y \in Y} y}{|Y|} > q$$

Inversion of CDF

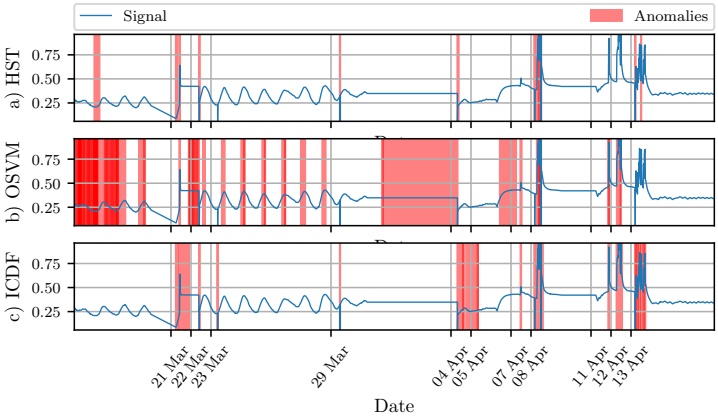


$$x_\mathrm{l} = F_X(1-q;\bar{x}_n,s_n)^{-1}$$
$$x_\mathrm{u} = F_X(q;\bar{x}_n,s_n)^{-1}$$

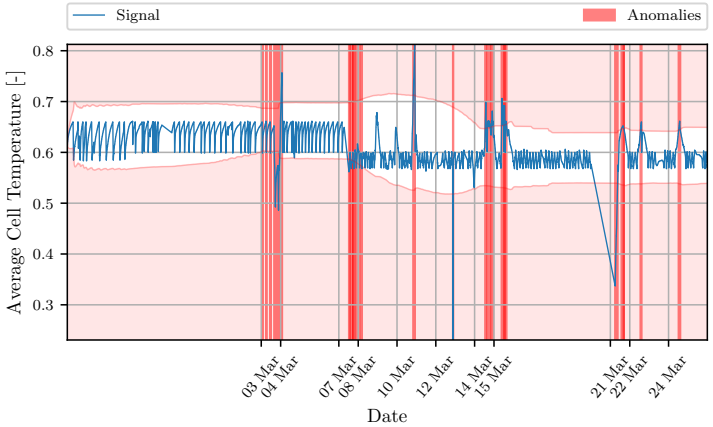
ICDF-based Outlier Detection - BESS



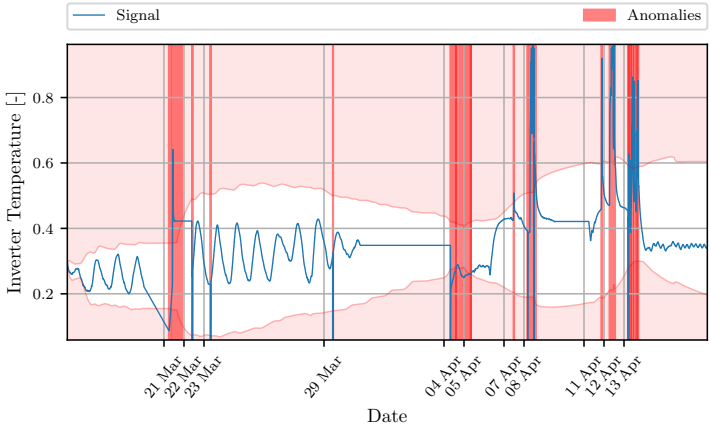
ICDF-based Outlier Detection - Inverter



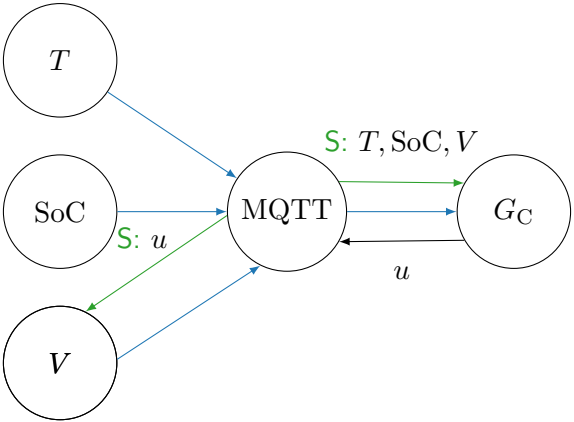
Dynamic Process Limits



Dynamic Process Limits



Utilize Existing Infrastructure



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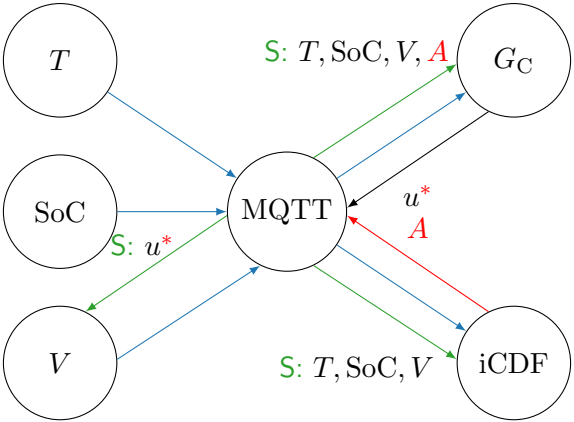

Summary

- automated alerting without prior knowledge of process limits
- assessment of environmental conditions and device aging
- self-learning approach using streamed data
- sets dynamic threshold for individual signals
- seamless integration with existing IT infrastructure

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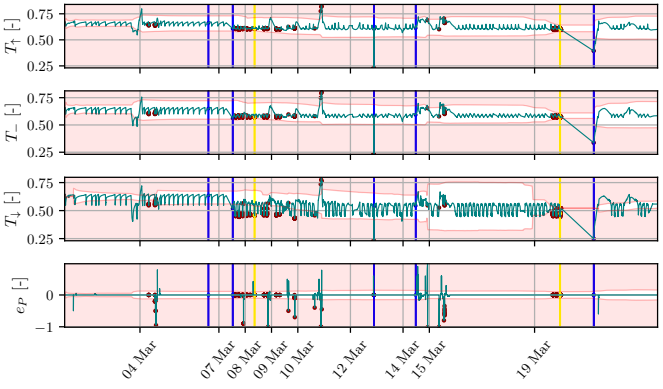
Follow-up research



[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 $x_{q,i}$

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) ;
  $x_{q,i} \leftarrow$ 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($x_{i-t_e}, \bar{x}, s^2, n$);
      $n \leftarrow n - 1$;
    end for
  end if
  $i \leftarrow i + 1$;
end loop