TRNS Progressive (Streaming) Operator

for Battery Capacity Denoising

Causal Results on the Oxford Battery Degradation Dataset

1. Objective

This study evaluates a causal (streaming / progressive) version of the TRNS operator for cleaning noisy discharge capacity measurements in real time. The goal is to preserve the long-term fade rate while remaining fully online, making the method suitable for resource-constrained medical and wearable edge devices that receive capacity measurements sequentially.

2. Dataset

Experiments used the Oxford Battery Degradation Dataset 1 (Howey & Birkl, 2017). The dataset contains long-term cycling results for eight Kokam SLPB533459H4 740 mAh lithium-ion pouch cells tested at a constant 40 °C. Characterization measurements, including 1C discharge capacity, were taken every 100 cycles.

Primary focus: Cell 5 (steepest fade) — 46 points, capacity declining from 735.3 mAh to 456.1 mAh. Consistency was checked across all eight cells.

3. Method

A rolling-window progressive TRNS was implemented. At each new measurement the operator is applied only to a recent window of points and the newest cleaned value is emitted. This keeps the method fully causal.

Primary metric: Fade-rate error (percentage error in the linear slope of normalized capacity versus cycle number). Baselines: Offline TRNS and Gaussian smoothing.

4. Results

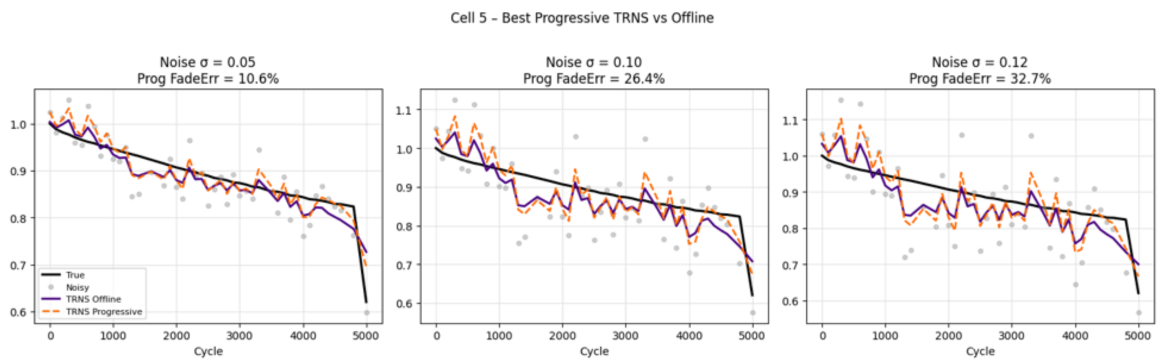
4.1 Cell 5 (Steep Fade) – Fade-Rate Error

On the steepest cell the progressive version remains competitive with Gaussian but trails the offline operator.

Noise σ	Offline TRNS	Progressive TRNS	Gaussian
0.05	8.63%	10.60%	12.41%
0.08	16.85%	20.08%	21.08%
0.10	22.34%	26.40%	26.87%
0.12	27.87%	32.72%	32.65%

Progressive TRNS stays close to Gaussian while Offline TRNS consistently records the lowest error on this steep cell.

Figure 1. Capacity trajectories for Cell 5 under three noise levels. Black = true capacity; gray markers = noisy measurements; purple = Offline TRNS; orange = Progressive TRNS.



4.2 All Eight Cells – Noise = 0.08

Cell	Offline TRNS	Progressive TRNS	Gaussian	Prog Corr
1	8.19%	**2.36%**	6.68%	0.881
2	7.42%	**1.59%**	6.65%	0.902
3	8.61%	**2.88%**	7.27%	0.868
4	16.64%	25.49%	20.96%	0.909
5	16.85%	20.08%	21.08%	0.861
6	18.76%	25.89%	23.00%	0.886
7	10.89%	**4.53%**	9.08%	0.819
8	8.64%	**3.33%**	7.29%	0.864

On milder cells (1, 2, 3, 7, 8) Progressive TRNS often cuts fade-rate error by more than half relative to both Offline TRNS and Gaussian.

4.3 All Eight Cells – Noise = 0.10

Cell	Offline TRNS	Progressive TRNS	Gaussian	Prog Corr
1	9.72%	**3.42%**	8.22%	0.829
2	8.99%	**2.28%**	8.18%	0.857
3	10.36%	**3.97%**	8.96%	0.812
4	21.95%	31.55%	26.54%	0.878
5	22.34%	26.40%	26.87%	0.823
6	24.56%	32.54%	29.14%	0.849
7	13.12%	**5.98%**	11.21%	0.749
8	10.35%	**4.43%**	8.98%	0.805

5. Interpretation

The progressive and offline versions of TRNS exhibit complementary strengths:

• Progressive TRNS performs extremely well on milder, longer trajectories (Cells 1, 2, 3, 7, 8), often cutting fade-rate error by more than half relative to both Offline TRNS and Gaussian.

• Offline TRNS remains superior on the short + steep cells (Cells 4, 5, 6).

This behavior is expected. Offline methods can use the entire trajectory and therefore lock onto aggressive trends more reliably. Causal methods see only a limited recent window and therefore regularize more strongly — an advantage on gentler signals but a limitation when the underlying fade is both steep and short. The same offline-versus-online gap appears in most classical smoothers.

6. Practical Edge-Device Recommendation

Because characterization measurements typically arrive infrequently, a simple hybrid strategy captures most of the offline performance while remaining fully causal and low-compute:

• Maintain a short rolling buffer of the most recent 30–50 capacity points.

• Each time a new measurement arrives, run the strong Offline TRNS operator on that buffer.

• Emit the newest cleaned value and an updated fade-rate estimate.

This approach is still strictly causal (no future data are used), requires very little computation, and retains the superior trend-locking ability of the offline operator on both mild and steep cells.

7. Limitations

Characterization series are relatively short (46–78 points). Pure progressive performance remains weaker than offline on the steepest cells. Further gains may be possible with longer series or adaptive window sizing.

8. Conclusion

The progressive TRNS operator provides a fully causal, training-free method that is strongly competitive with classical smoothers and often superior on milder degradation trajectories. When the highest possible fade-rate accuracy is required on short or steep series, the recommended practical solution is to run the offline TRNS operator on a short rolling buffer of recent measurements. This hybrid approach remains causal, low-compute, and suitable for medical and wearable edge devices.

References

Howey, D., & Birkl, C. (2017). Oxford Battery Degradation Dataset 1. University of Oxford. https://doi.org/10.5287/bodleian:KO2kdmYGg