



Lightweight Physics-Informed Reservoir Computing for Battery Health Prediction



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Introduction

Safe operation of electric vehicles relies heavily on **lithium-ion batteries**. Predicting a battery's state of health (SOH) is safety-critical to prevent thermal runaway and extend lifespans. Current models [1, 2] force a compromise between computational speed and physical information.

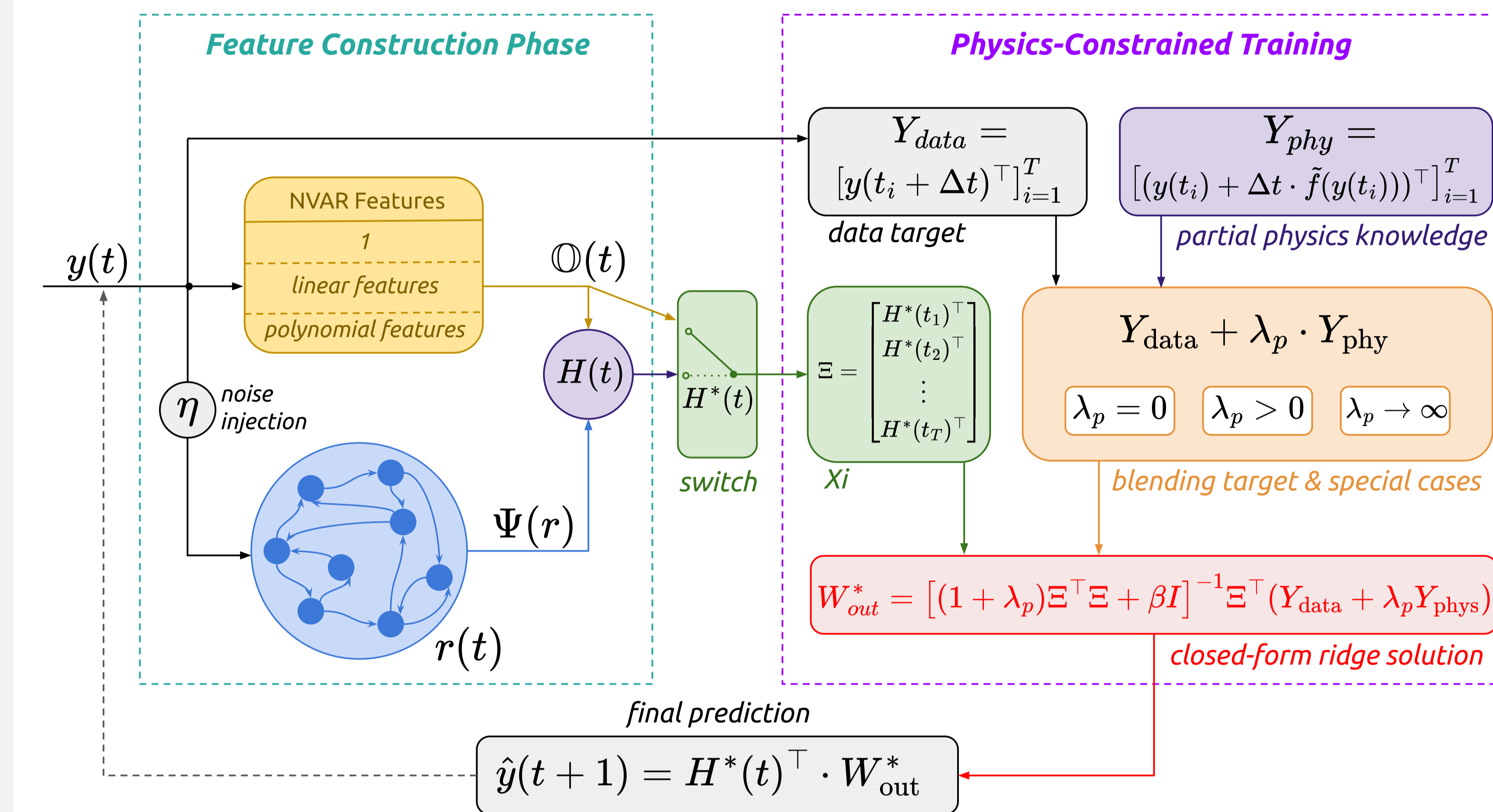
Objectives

- Design a **lightweight framework** with a closed-form solver.
- Make best use of available **prior-physics** knowledge.
- **Energy efficient**, accurate SOH monitoring directly on edge hardware.

Approach

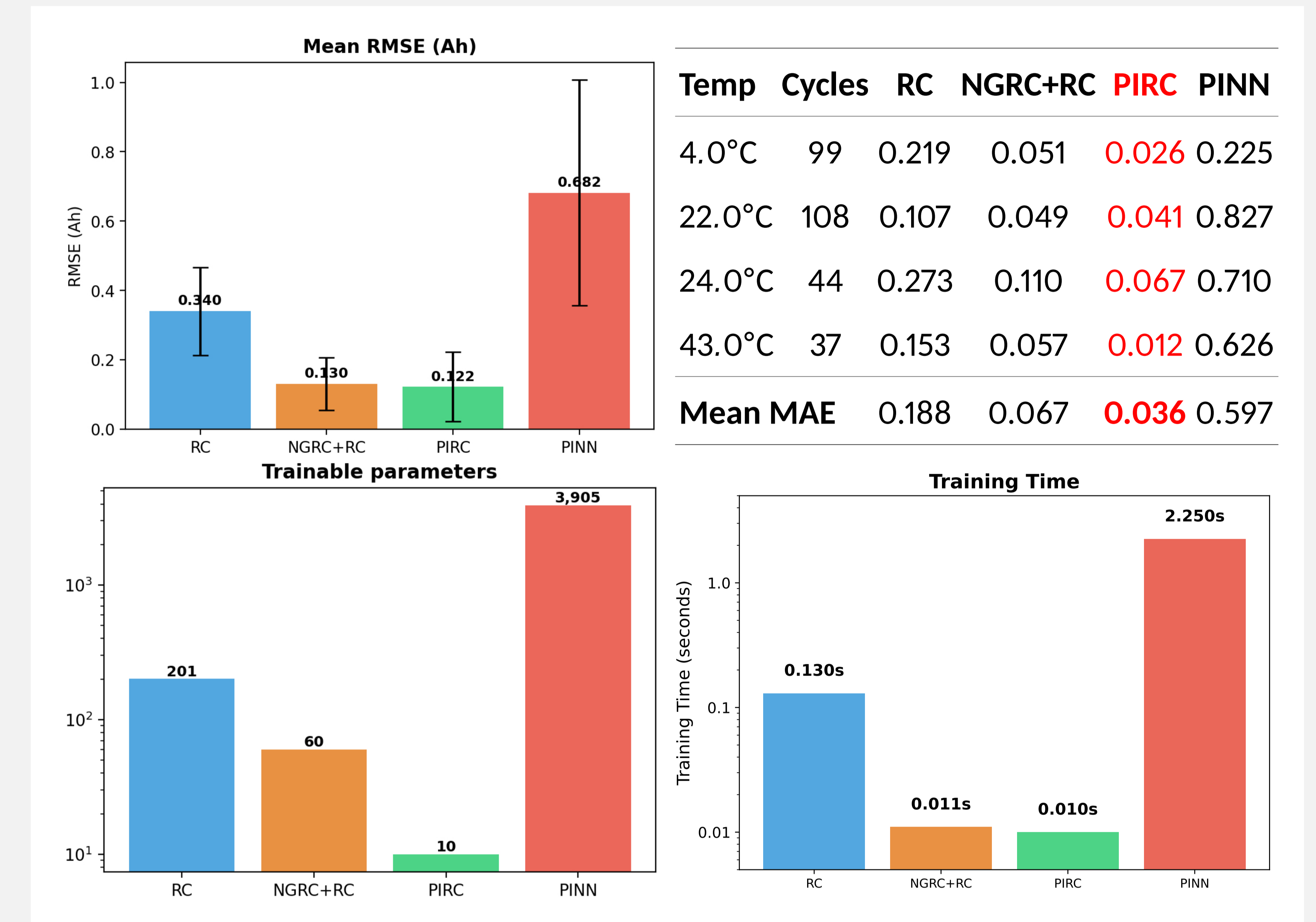
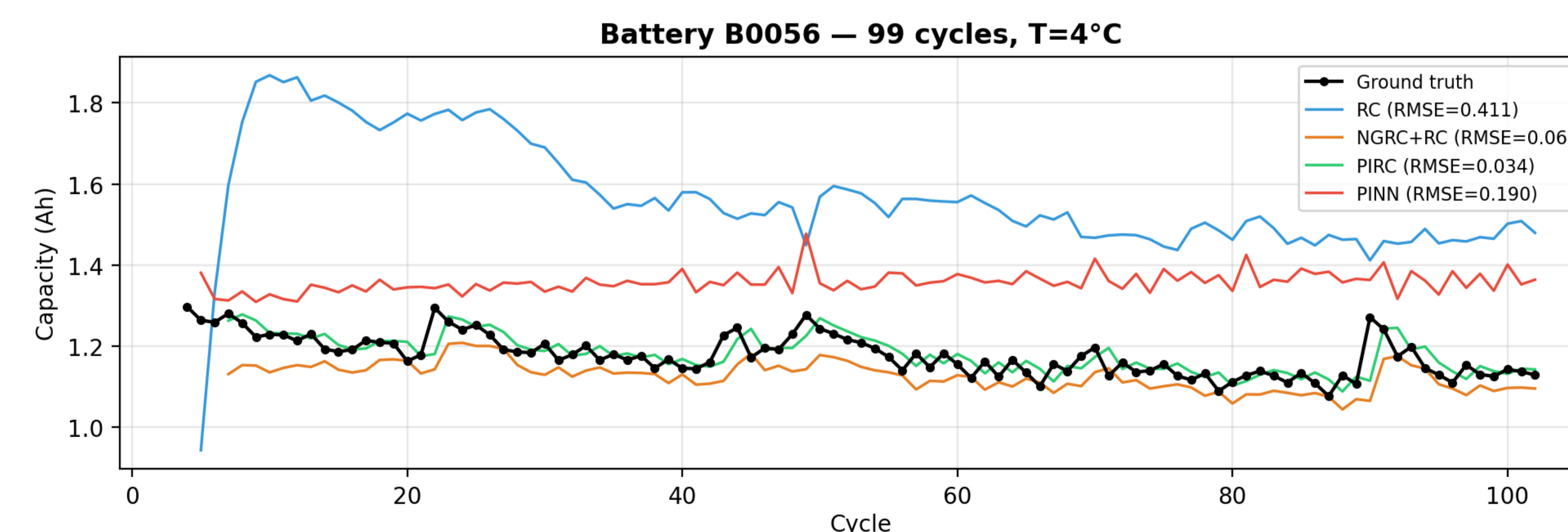
- To **bridge the gap** between computational speed and physical consistency, we introduce the PIRC framework.
- PIRC generates **two sets of features** from input: explicit polynomial NVAR features & recurrent reservoir states
 - PIRC has **adaptive switching mechanism** which selects the minimal features to prevent over-parameterization
 - The readout weight is found by **closed-form ridge regression**, avoiding costly backpropagation.

PIRC Architecture



Results

We evaluated PIRC on the **NASA PCoE battery aging dataset** [3] across four batteries at temperatures ranging from 4°C to 43°C. PIRC records the smallest RMSE and trainable parameters and tracks complex capacity-regeneration spikes better than any other model.



Conclusion & Future Work

PIRC achieves **better prediction accuracy** while remaining **lightweight**. Future work will focus on establishing stability guarantees and on developing a generalizable Bayesian extension of the PIRC framework [4].

References

- [1] M. Raissi, P. Perdikaris, and G. E. Karniadakis, "Physics-informed neural networks," *J. Comput. Phys.*, vol. 378, p. 686–707, 2019.
- [2] R. Chepuri et al., "Hybridizing traditional and next-generation reservoir computing to accurately and efficiently forecast dynamical systems," *Chaos*, vol. 34, no. 6, p. 063114, 2024.
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- [4] K. Anurag, K. Azizi, F. Sorrentino, and W. Wan, "RCUKF: Data-Driven Modeling Meets Bayesian Estimation," *IFAC-PapersOnLine*, vol. 59, no. 30, p. 287–292, 2025.