HYBRID AI-DRIVEN SOC AND SOH ESTIMATION FOR BATTERY MANAGEMENT SYSTEMS

Dheeraj Reddy Pasham, Robotics and Autonomous Systems(Electrical Engineering)

Mentor: Dr. Junfeng Zhao, Assistant Professor

Engineering, The Polytechnic School

RESEARCH QUESTION:

Modern battery management systems (BMS) require precise state-of-charge (SOC) and state-of-health (SOH) estimation to ensure safety and performance, especially as battery demands increase in applications like electric vehicles and renewable energy storage. Traditional physics-based models, while grounded in solid principles, often struggle with real-time nonlinearities and parameter variations, and conventional machine learning methods can fall short when capturing the temporal complexities of battery data. In contrast, our hybrid AI-driven approach fuses a Bidirectional LSTM network with an Unscented Kalman Filter, combining deep learning's ability to extract complex patterns with the robustness of adaptive filtering. This integration enhances estimation accuracy, mitigates noise effects, and dynamically adapts to battery degradation, offering a superior alternative for next-generation BMS.

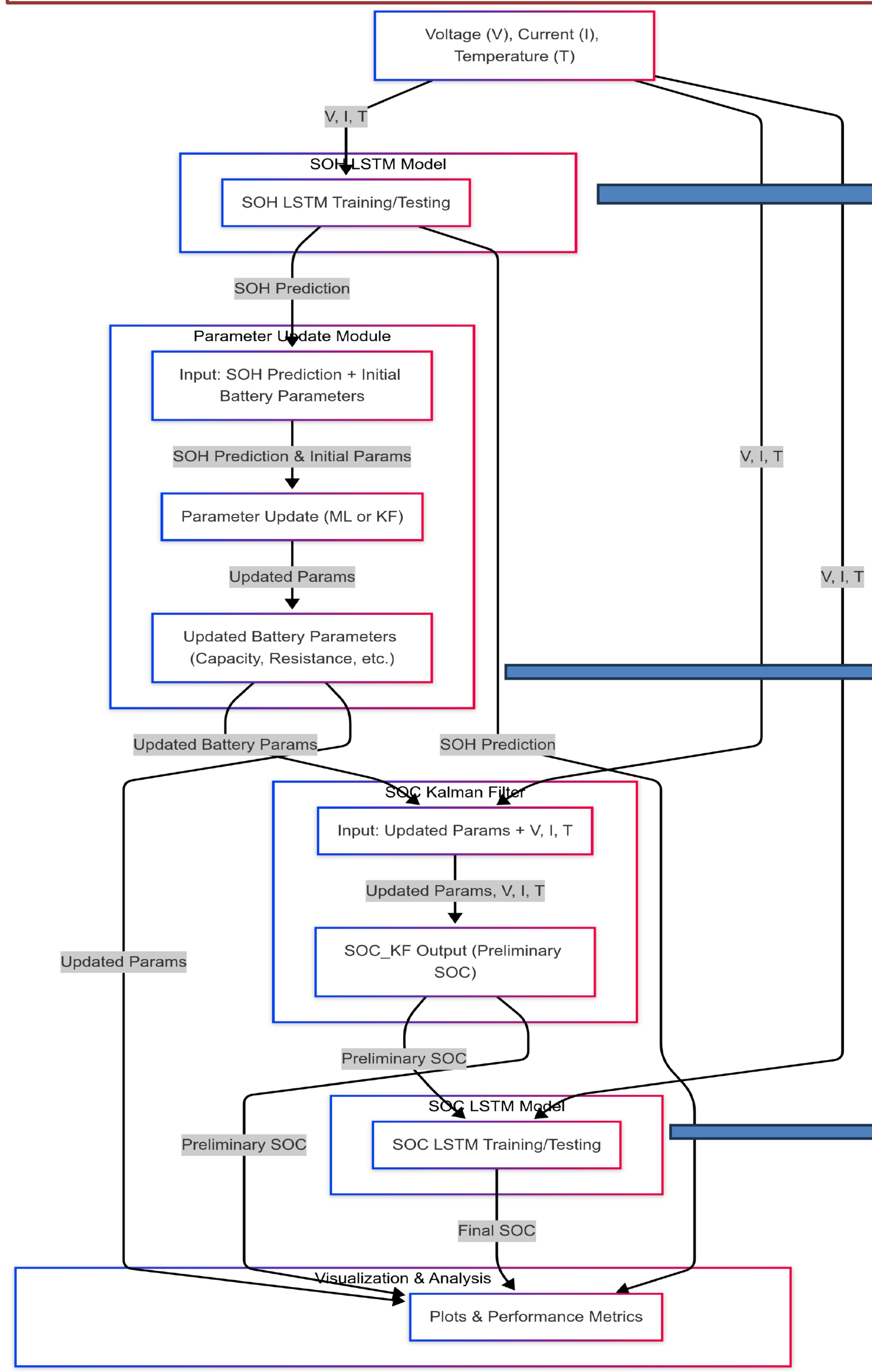
METHODOLOGY:

- Literature Review:
  - **Surveyed current physics-based and machine learning methods for SOC/SOH estimation.**
  - **Highlighted gaps in handling nonlinear dynamics and real-time adaptability.**
- Finalising Architecture:
  - **Designed a hybrid architecture merging a Bidirectional LSTM with an Unscented Kalman Filter.**
  - **Iteratively refined the design based on literature insights and simulation results.**
- Finding Datasets:
  - **Collected battery cycling data along with sensor measurements (voltage, current, temperature).**
  - **Selected datasets that cover diverse operational conditions for robust training.**
- Dataset Preprocessing:
  - **Normalized and denoised the data to remove inconsistencies and outliers.**
  - **Prepared clean and consistent inputs for effective model training.**
- Training Models:
  - **Trained the Bi-LSTM network to capture temporal battery behaviors and initial SOC/SOH predictions.**
  - **Calibrated the UKF to refine these predictions, ensuring dynamic parameter updates.**
- Testing Models:
  - **Evaluated the hybrid model using metrics like RMSE and MAE.**
  - **Compared results with conventional models to validate improved accuracy and robustness.**

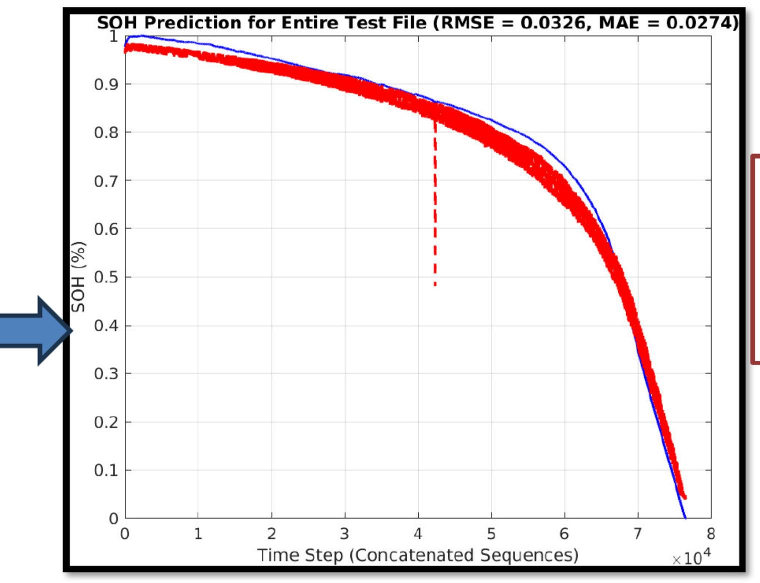
Future Directions:

- **Explore real-time deployment on embedded systems and extend the hybrid model to accommodate diverse battery types and operational conditions for further improved accuracy and adaptability.**

ARCHITECTURE:

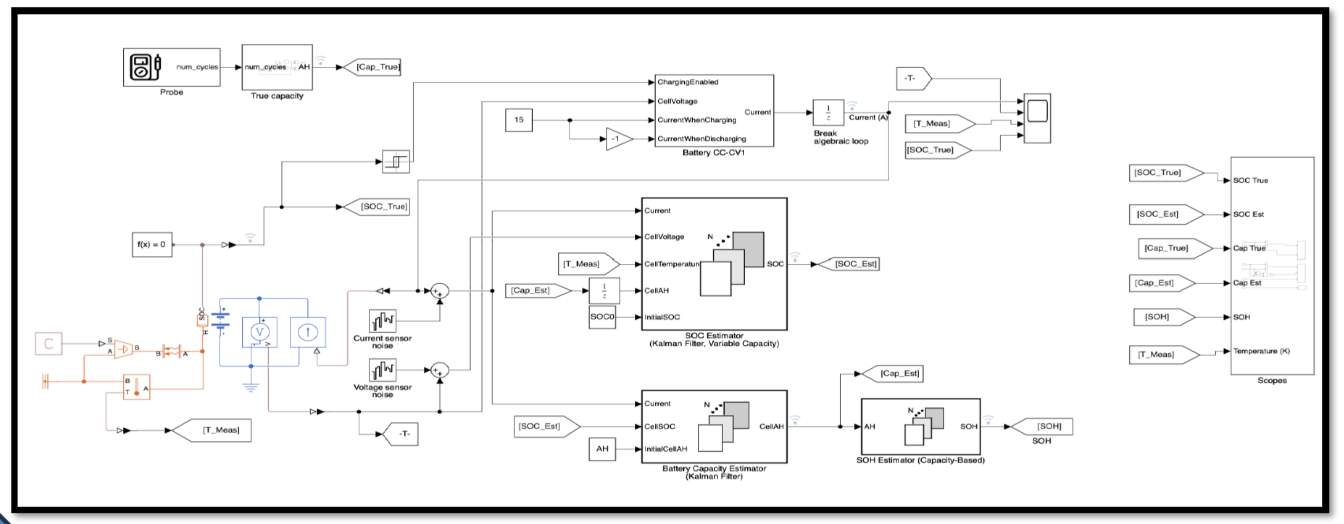


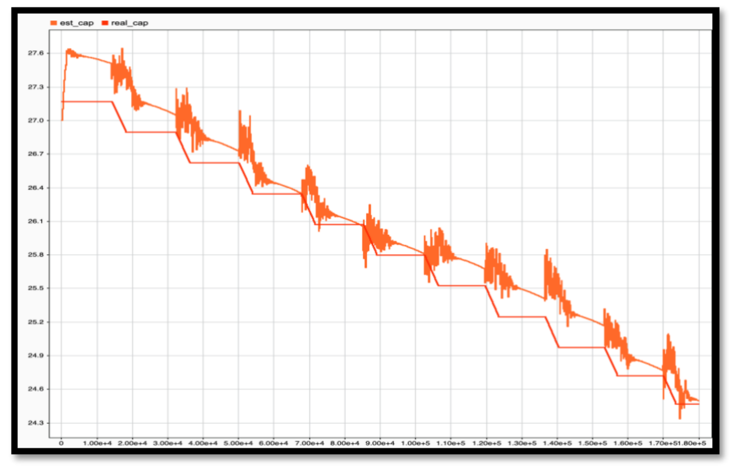
RESULTS:



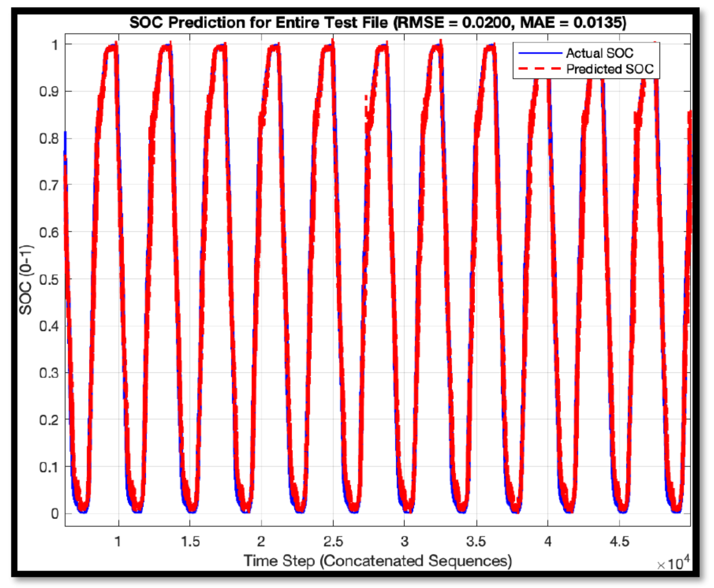
Final Test RMSE: 0.0326
Final Test MAE (SOH Error): 0.0274

(a)LSTM SOH ESTIMATION





(b)KF – CAPACITY ESTIMATION



Final Test RMSE: 0.0200
Final Test MAE (SOC Error): 0.0135

(c)LSTM SOC ESTIMATION

CITATION:

1.Paul Takyi-Aninakwa, Shunli Wang, Hongying Zhang, Huan Li, Wenhua Xu, Carlos Fernandez, An optimized relevant long short-term memory-squared gain extended Kalman filter for the state of charge estimation of lithium-ion batteries

2.Tian-E Fan, Song-Ming Liu, Xin Tang, Baihua Qu, Simultaneously estimating two battery states by combining a long short-term memory network with an adaptive unscented Kalman filter

3.Fangfang Yang, Shaohui Zhang, Weihua Li, Qiang Miao, State-of-charge estimation of lithium-ion batteries using LSTM and UKF, Energy

MORE
Masters Opportunity for Research in Engineering

ASU Ira A. Fulton Schools of Engineering
Arizona State University