Battery Capacity Prediction using Neural Network Methods

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Introduction

Battery capacity is a key indicator of battery health and degrades over time due to factors such as temperature, charging rate, and depth of discharge. Owing to complex and time-varying nature, accurately predicting battery capacity is vital for ensuring safety, optimizing lifetime, and improving range estimation in electric vehicles.

Traditional model-based approaches often struggle to generalize under real-world conditions. Neural network–based methods, particularly Long Short-Term Memory (LSTM) and Gated Recurrent Unit (GRU) models, provide a data-driven solution capable of learning complex nonlinear and temporal patterns directly from operational data, enabling more accurate and adaptive capacity prediction.

Figure 1: Battery capacity prediction [This is an AI generated image]

Neural Network Architecture

LSTM Architecture

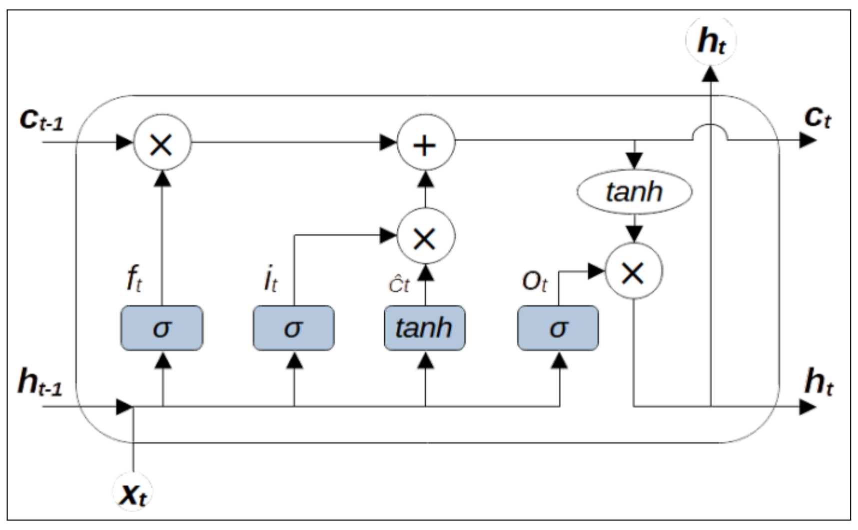

Figure 2: LSTM architecture [1]

Equations

$$f_t = \sigma_g\left(W_f x_t + U_f h_{t-1} + b_f\right)$$
$$i_t = \sigma_g\left(W_i x_t + U_i h_{t-1} + b_i\right)$$
$$o_t = \sigma_g\left(W_o x_t + U_o h_{t-1} + b_o\right)$$
$$c_t = f_t \circ c_{t-1} + i_t \circ \sigma_c\left(W_c x_t + U_c h_{t-1} + b_c\right)$$
$$h_t = o_t \circ \sigma_h\left(c_t\right)$$

GRU Architecture

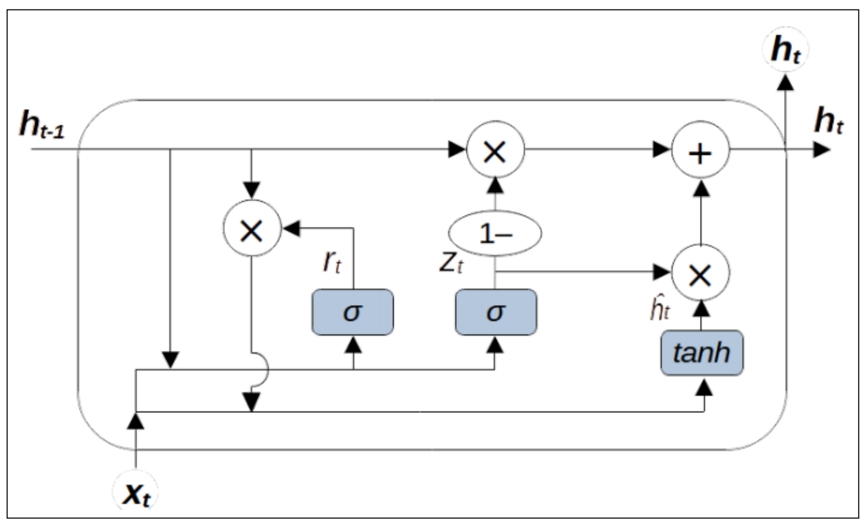

Figure 3: GRU architecture [1]

Equations

$$z = \sigma\left(W_z x_t + U_z h_{t-1} + b_z\right)$$
$$r = \sigma\left(W_r x_t + U_r h_{t-1} + b_r\right)$$
$$\tilde{h} = \tanh\left(W_h x_t + r \cdot U_h h_{t-1} + b_z\right)$$
$$h = z \cdot h_{t-1} + (1 - z) \cdot \tilde{h}$$

Approach

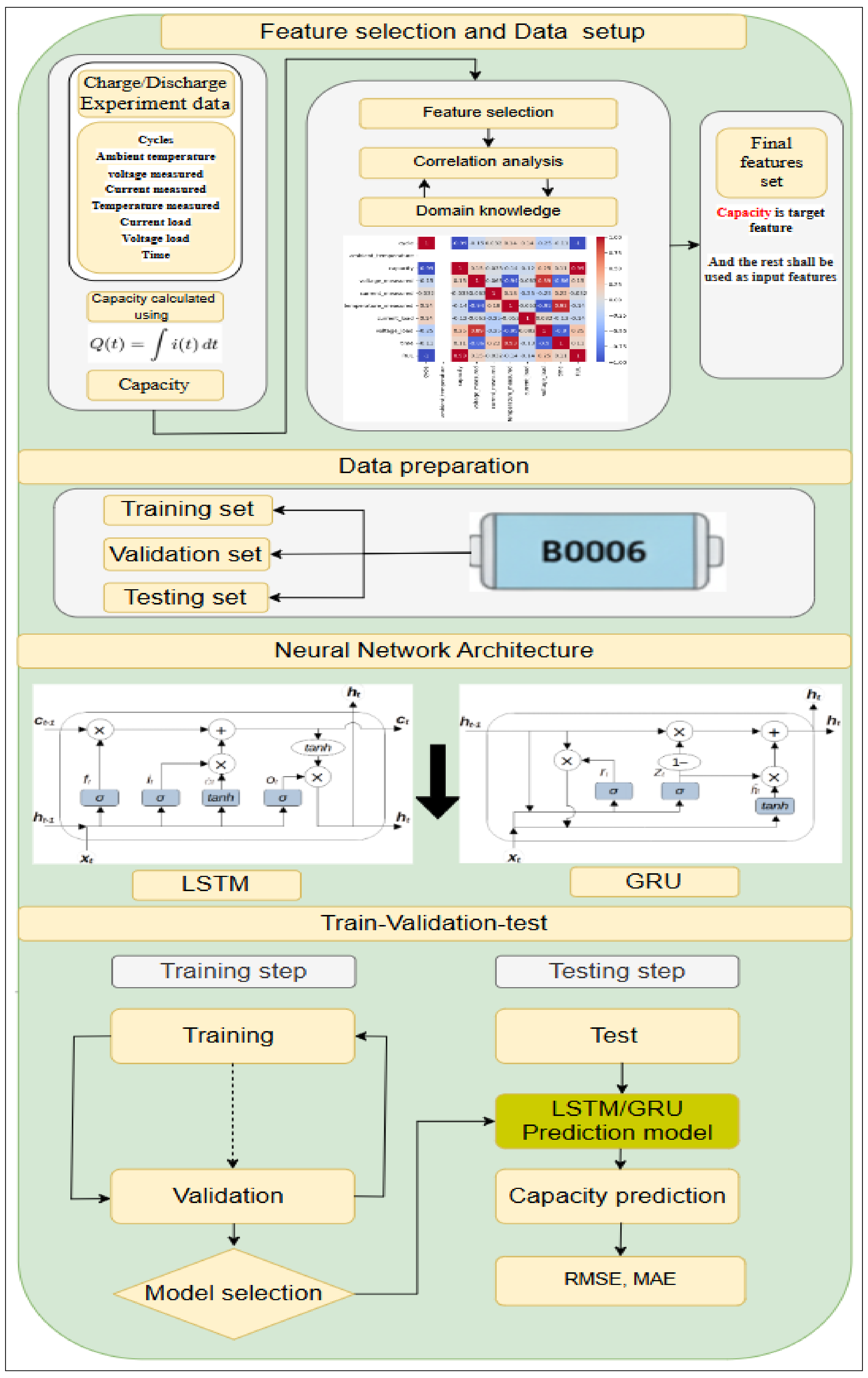

Figure 4: Approach for the battery capacity prediction

There are different approaches followed to develop generalized battery capacity prediction, they are Single channel and Multi-channel (with K-fold cross validation) given in [1], both methods have its owns pros and cons, here single channel method is followed. This approach is a generalized Capacity prediction model for individual battery.

Results

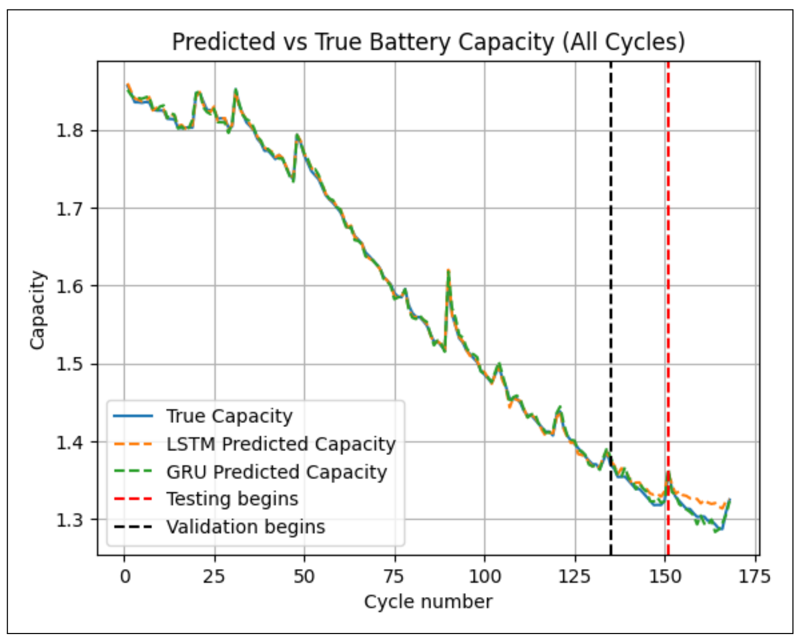

Figure 5: Prediction plot against all data

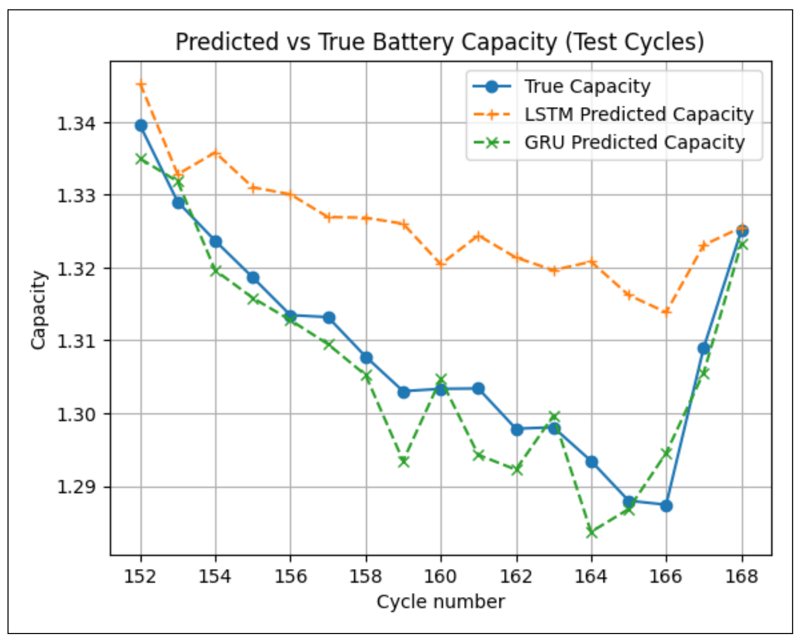

Figure 6: Prediction plot against testing data

Metric	LSTM	GRU
RMSE	0.0051	0.0051
MAE	0.0168	0.0042

Table 1: Performance comparison of LSTM and GRU models

References

[1] A. R. Y. et al., "Remaining useful life prediction of lithium-ion battery based on LSTM and GRU," in *Proceedings of the 2021 International Conference on Computer, Control, Informatics and Its Applications (IC3INA)*, 2021.

[2] K. Park, Y. Choi, W. Choi, H. Ryu, and H. Kim, "LSTM-Based Battery Remaining Useful Life Prediction with Multi-Channel Charging Profiles," *IEEE Access*, 2020.

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