Real World Load Cycle Based State of Charge Estimation Using Neural Network

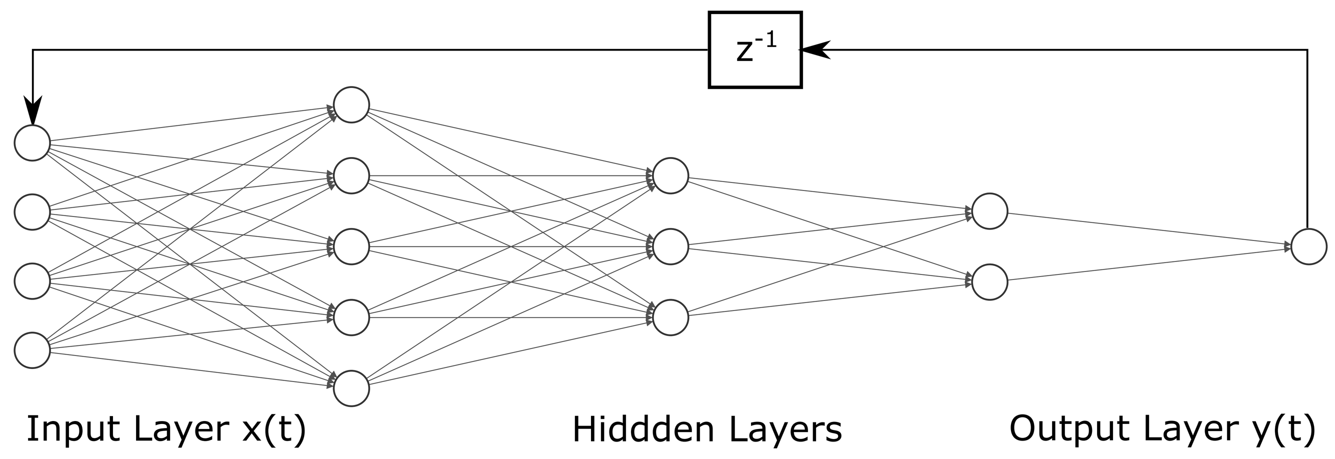
Franke, Marcel; Kowal, Julia

TU Berlin, Electrical Energy Storage Technology, Einsteinufer 11, D-10587 Berlin

Abstract

Although lead-acid batteries have been used for more than 100 years, determining their state of charge (SoC) remains a challenging task. Current dependent capacity, multiple side reactions and strong non-linear behaviour impede the prediction of the SoC with common methods. Machine learning techniques are evolving and have become very prominent in battery state estimation. In this study a non-linear autoregressive neural network (NARX) is used to determine the SoC of a lead-acid battery. The focus lies on accurate training dataset creation based on real world load cycles similar to a method developed in [1].

Neural Network Architecture

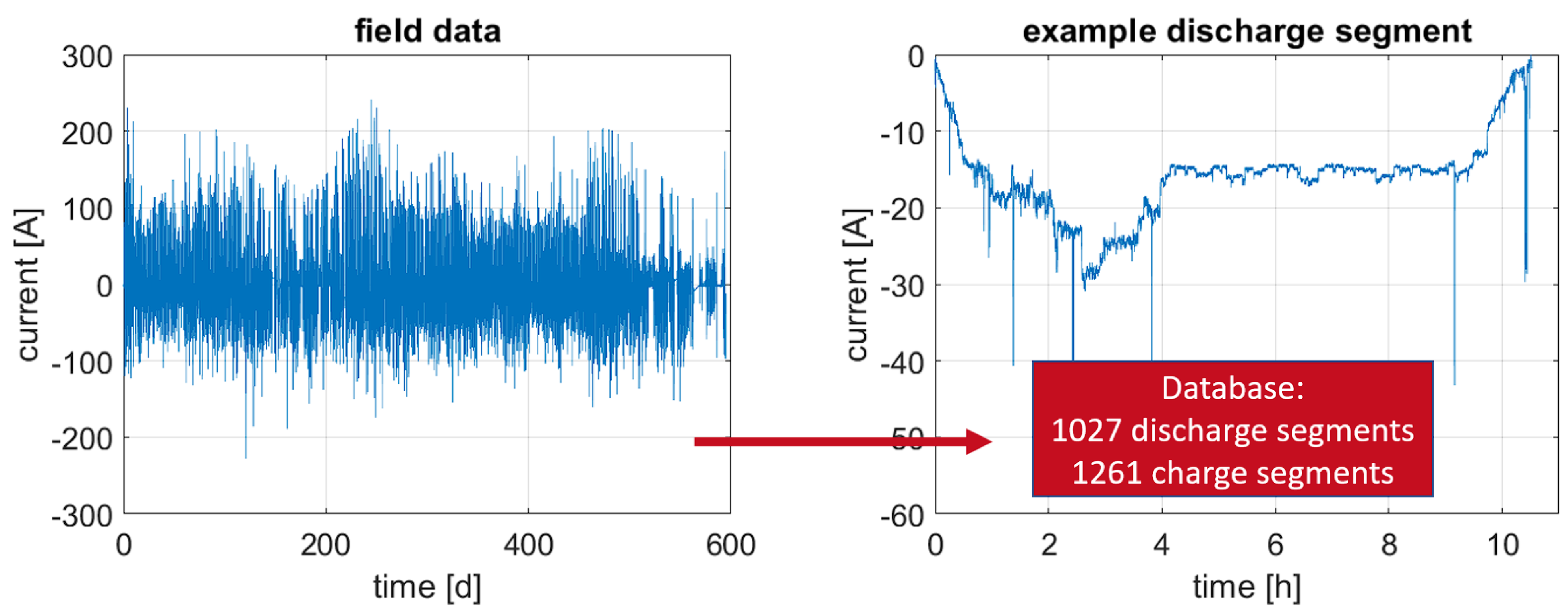


- NARX network with feedback loop
- input: $x(t) = \begin{pmatrix} u(t) \\ i(t) \\ \delta u(t)/\delta t \\ SoC(t-1) \end{pmatrix}$, output: $y(t) = SoC(t)$

Dataset Creation

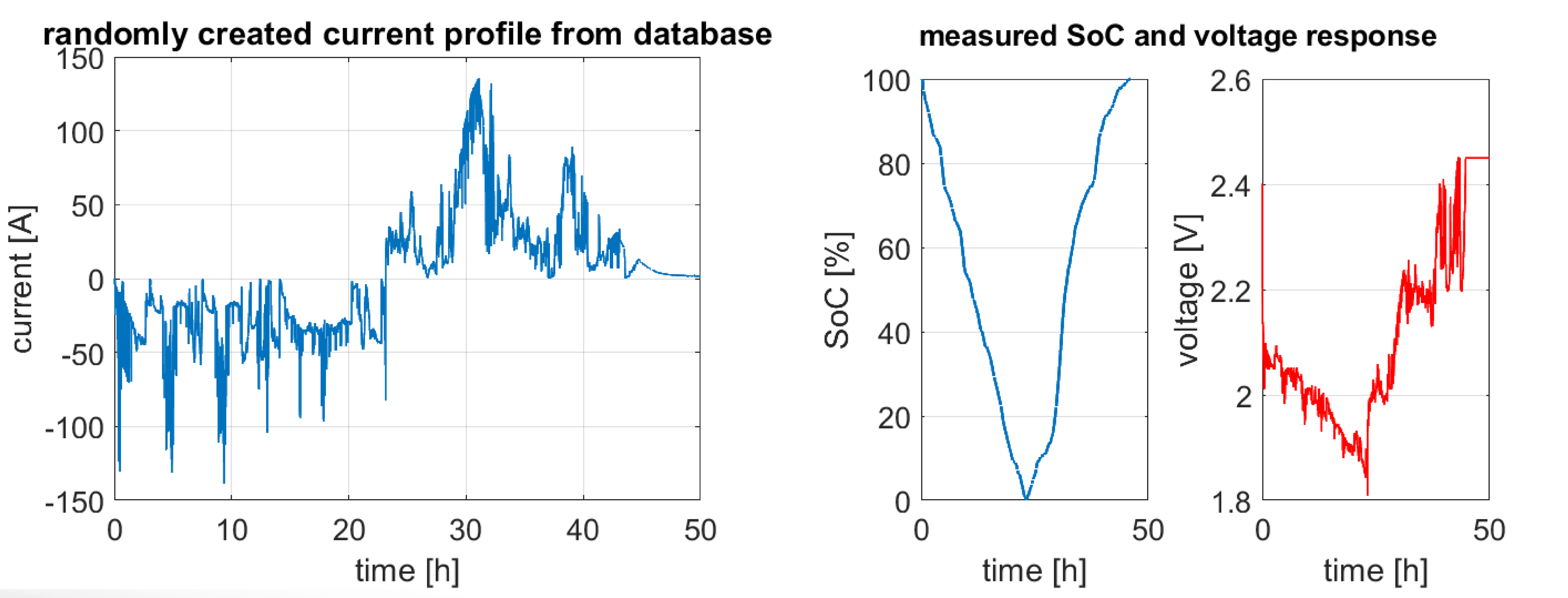
Database

- field data from an off-grid energy storage system
- all charge/discharge segments longer 30 min are merged in database



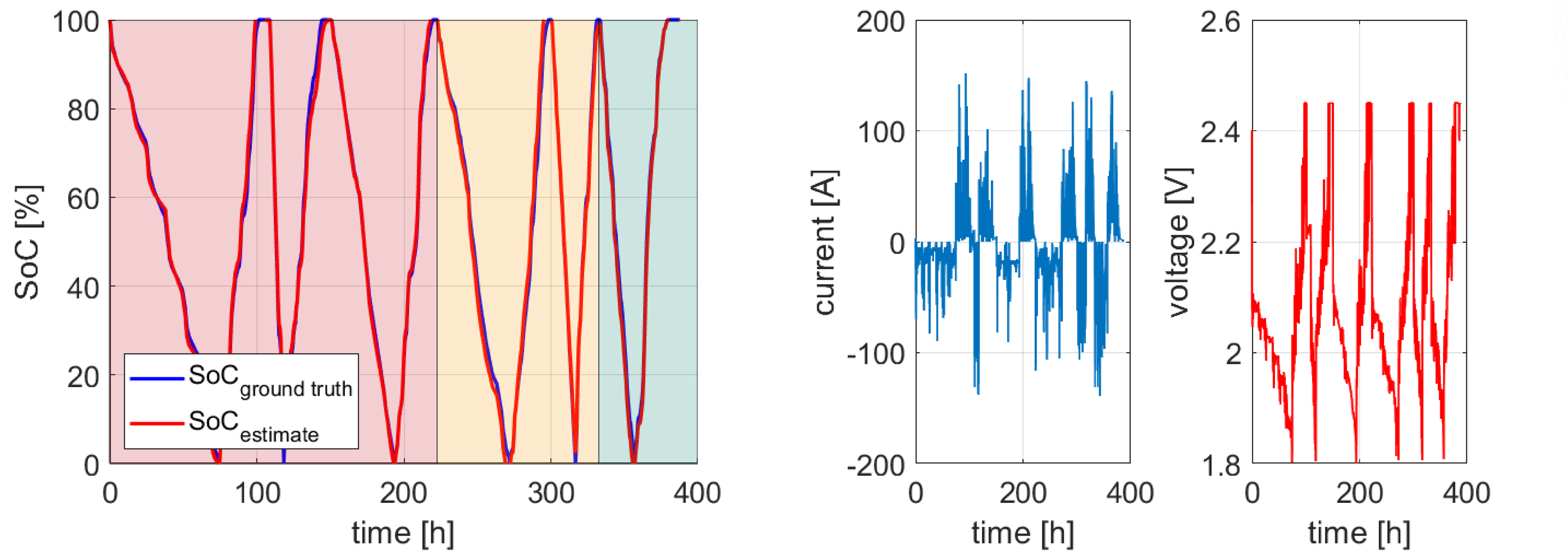
Profiles

- SoC limit definition:
  - $100\,\%$ @ charge factor > 1.03 & current < $5\,\mathrm{A}$
  - $0\,\%$ @ $1.8\,\mathrm{V}$ cut-off voltage
- charge/discharge segments from database are combined randomly
- current only changes at cut-off to determine SoC-reference accurately



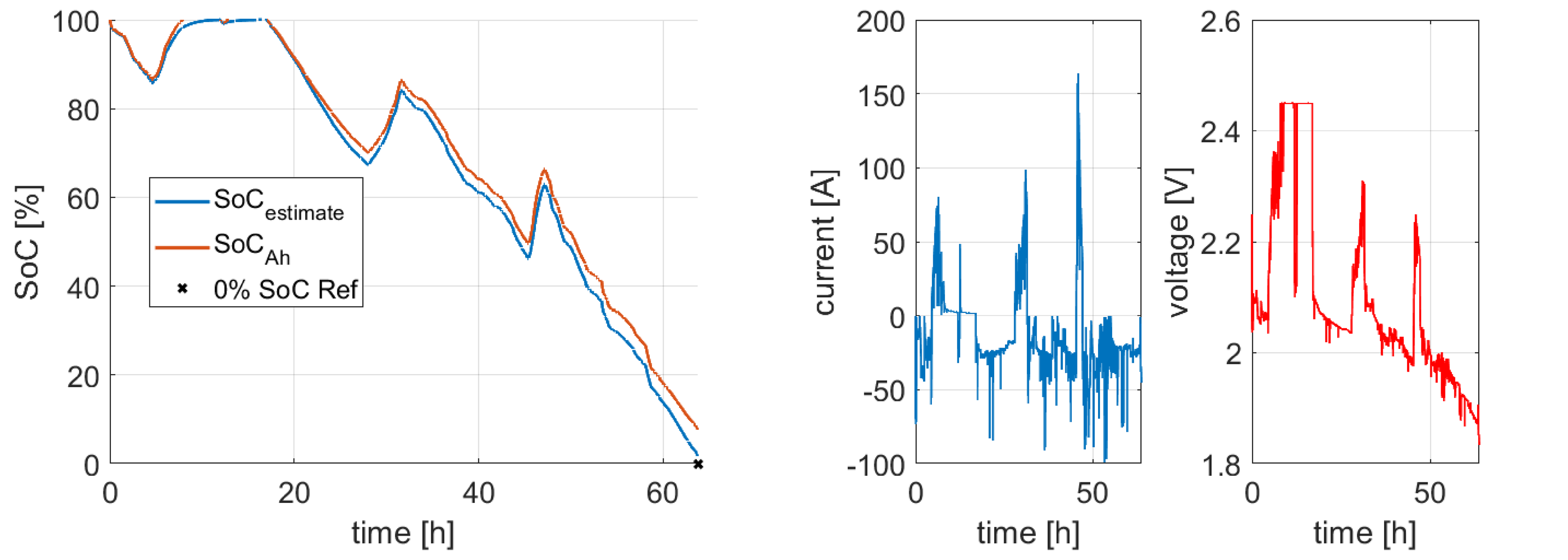
Network Training

- profiles are arranged in training (r), validation (y) and test (g) data with varying discharge capacity ($662\,\mathrm{Ah}$ to $864\,\mathrm{Ah}$)
- training is performed with open loop network
- total Ah-throughput per cycle is used for SoC-reference
- overall RMSE is < $2\,\%$ SoC

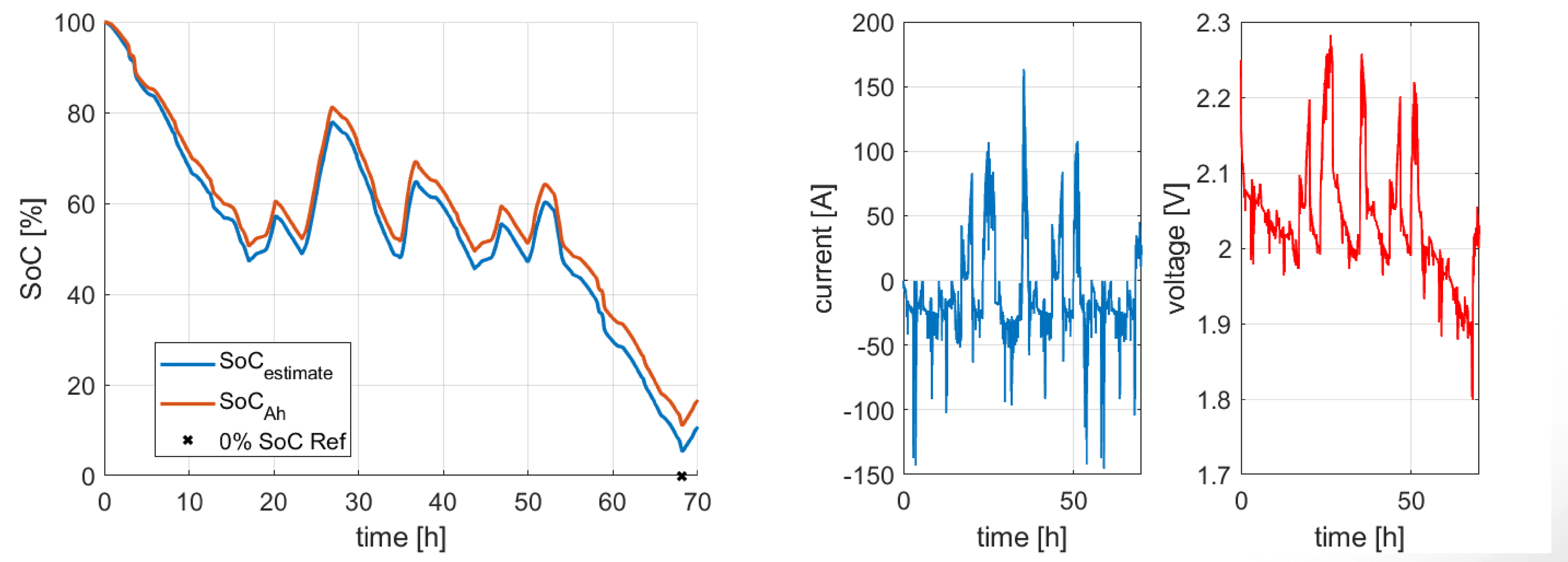


Validation

- two new partial SoC profiles created from database
- Ah-counting cannot be used as true reference because charge efficiency of battery is SoC-dependent
- SoC value at $0\,\%$ is used as true reference



Profile 1: error at reference point is $1.6\,\%$ for the NARX and $7.5\,\%$ for Ah-counting



Profile 2: error at reference point is $5.3\,\%$ for the NARX and $9.7\,\%$ for Ah-counting

Conclusion

The proposed method shows that current profiles created from real word cycle data can be used to train a neural network for SoC-prediction. The trained network is able to predict the SoC up to $6\,\%$ more accurate than common Ah-counting methods. Although the overall RMSE is small for the training dataset, the maximum error for a partial SoC profile is still > $5\,\%$ at the end of discharge.

References

[1] Quirin Kellner, Elham Hosseinzadeh, Gael Chouchelamane, Widanalage Dhammika Widanage, and James Marco. Battery cycle life test development for high-performance electric vehicle applications. *Journal of Energy Storage*, 15:228–244, 2018.

contact: marcel.franke@tu-berlin.de

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