Using Machine Learning to predict short-circuits in a pack of lithium-ion batteries

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1. Introduction

- Due to the increasing world-wide reliance on energy storage through lithium-ion batteries, the risk of short-circuits and consequently thermal runaway is becoming a more prominent issue.
- Short circuits occur when the positive and negative anodes in the battery are connected either via dendrites that grow due to extended use over long periods of time and pierce the separator or through the battery being damaged and the separator being pierced.
- Monitoring this issue means ensuring battery packs are undamaged and are replaced after heavy usage over long periods of time.

2. Equations

The fundamental equations used to create the lumped parameter thermal model in this project are as follows:

$$\frac{dT(j)}{dt} = \frac{Q_{battery}(j) - Q_{delta}(j)}{cv},$$

where,

$$Q_{battery}(t) = \frac{(V - V_{ocv})^2}{R},$$

and,

$$Q_\delta(j) = hA_{\text{env}}(j)(T(j) - T_{\text{env}}) + h_{bb}A_{\text{bb}}(j)\sum_{\text{adj}}(T(j) - T_{\text{adj}})$$

If battery j will short circuit,

$$R(j) = e^{t/t_{dg}}$$

- c is the thermal capacity of the battery and v is the volume of the battery
- V is the voltage drop across the battery when connected in the circuit, V_{ocv} is the open circuit voltage and R is the internal resistance of the battery.
- h_{env} is the heat transfer coefficient between a surface on a battery and the environment and h_{bb} is the heat transfer coefficient between two battery surfaces in direct contact.
- A_{bb} is the total area of the battery in contact with another battery surface and A_{env} is the total area of a battery in contact with the - environment.
- T is the temperature of a battery and T_{env} is the temperature of the environment.

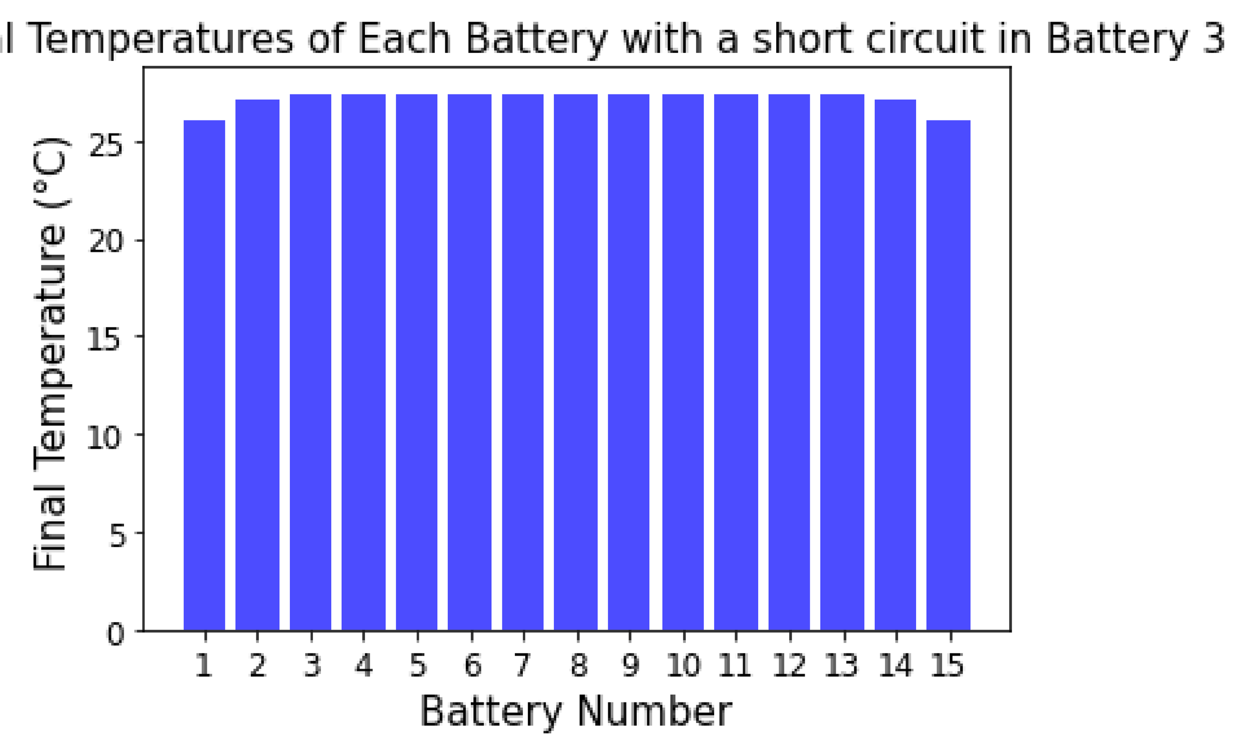
3. Lumped parameter thermal model

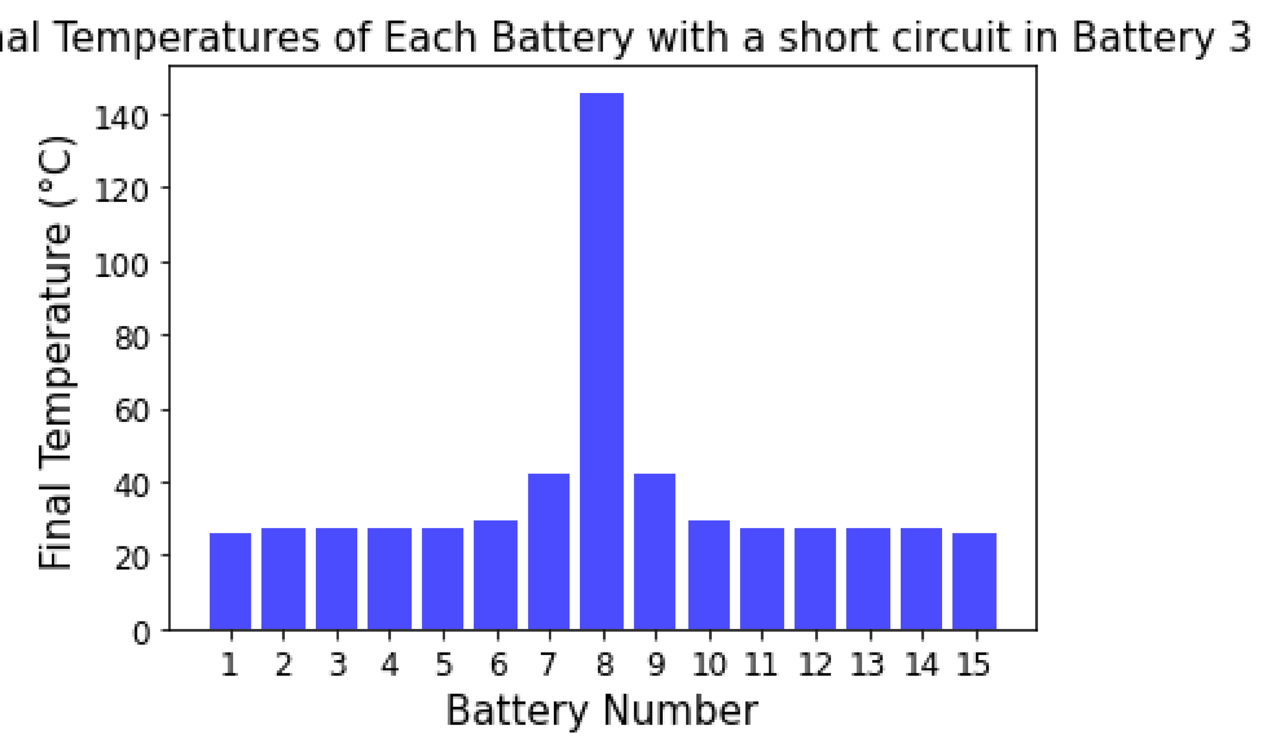
1. Main model assumptions and method:

- A lumped parameter thermal model is used in this project.
- Based on a "brick" of batteries (connected in parallel), typical of electric vehicle batteries.
- Model uses a brick consisting of 15 batteries.
- Middle battery is modeled to contain a short circuit.
- Resistance of that battery is time-dependent, varying with dendrite growth times.

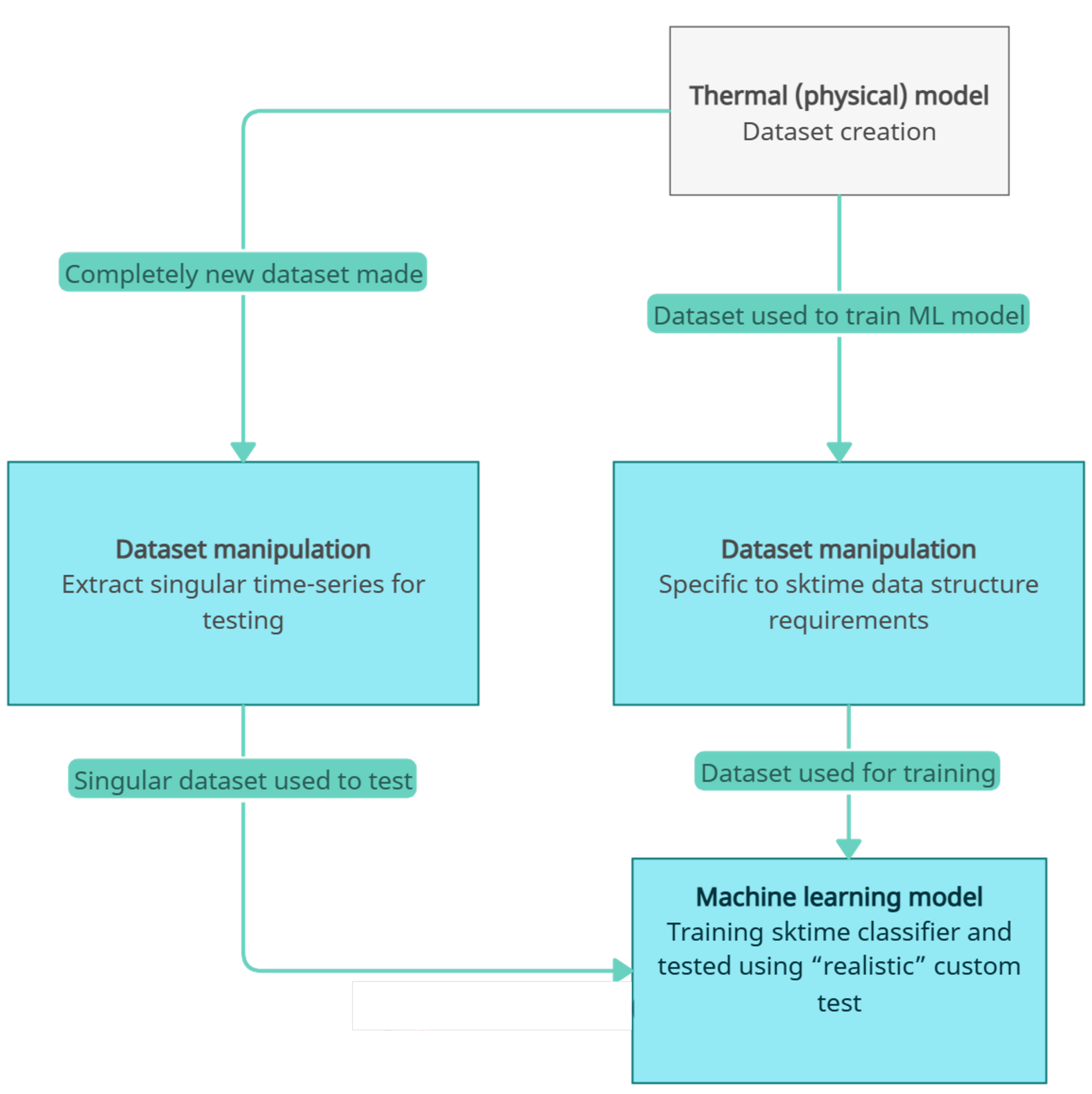
2. Model assumptions

Various assumptions have to be made in order to simplify the model for usage such as:
- Each battery is assumed to be cuboidal in shape.
- It is assumed that the conductivity between surfaces in contact with another battery is greater than conductivity with the surrounding environment.
- Room temperature is assumed to be 20 °C.





4. Machine Learning model



Dataset creation
- Thermal model generates datasets for training and testing.
- Data stored as ".csv" files for ML processing.

Data preprocessing
- "sktime" requires a specific data format.
- Two datasets: one for training, another with different parameters for realistic testing.
- Test dataset simulates real-world usage by extracting a single time series.
- Time series is divided into sliding "windows" for more realistic evaluation.

ML Model training and testing
- **Rocket Classifier** from sktime used for classification.
- Trained on the main dataset, tested on a separate single time series dataset.
- Accuracy is measured by the percentage of correct short-circuit predictions.

Key Steps:
- Data generation using a thermal model
- Preprocessing data to fit scikit-time requirements
- Training and testing the classifier with custom realistic test sets

5. Conclusions and Future Work

Key Findings: Machine learning can accurately predict short circuits in lithium-ion batteries, with potential applications in battery management systems and improving safety.

⚠ **Limitations:** Tested only on **simulated data**; real battery packs have a **complex architecture** that may affect predictions.

Future Work: Test on **real battery pack data** and improve detection with real-time **voltage fluctuations**.

References

Need to add references!!