Master thesis proposals for the Department of Control Engineering and System Analysis (SAAS)

Academic year 2024-2025

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1.Degradation detection and localization in battery packs

Supervising team

Maxime Bussios and Michel Kinnaert, Maxime.Bussios@ulb.be, Michel.Kinnaert@ulb.be, SAAS, ULB

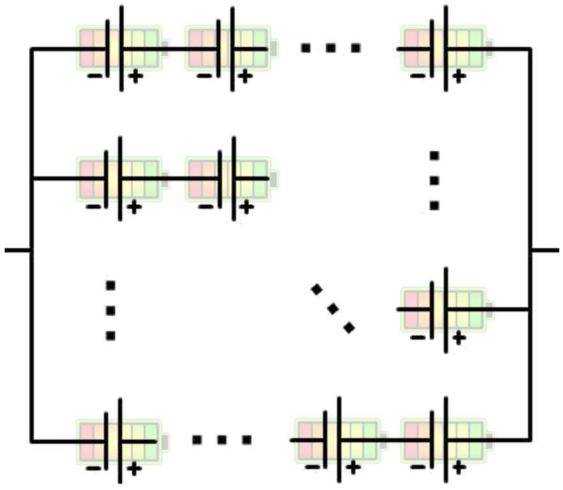
Context of the work:

Renewable energies and electric transportation are the cornerstones for developing a sustainable future society. Energy storage is fundamental in this context, in order to store surplus of energy and use it when the wind does not blow or the sun does not shine, or to produce vehicles that do not pollute the environment when they are on the roads.

Among the possibilities, lithium-ion batteries are the technology of choice given their high energy capacity and efficiency. However in contrast with other battery technologies, the benefits of lithium-ion batteries come at the price of careful monitoring requirements. Indeed, faulty cells in a battery pack can have catastrophic consequences including fire.

Objective of the thesis

The objective of this thesis is to develop a monitoring system that is able to detect and localize the degraded or weak cells within a pack on the basis of available voltage, current and temperature measurements. Both synthetic data obtained from a realistic battery pack simulator, and real data recorded on a 4-cell battery pack will be exploited to determine features that can be extracted from the measurements, or from combinations of measurements, and that exhibit pack malfunction. Next, appropriate classification tools will be investigated in order to decide on the healthy or degraded state of the pack and to localize the degraded cell/cells by processing the features extracted from the measurements. Various degradation levels and types will be considered in order to characterize the sensitivity to each fault.



Schematic of a battery pack.

Work to be done

The student should

1. perform a bibliographic search on fault/degradation diagnosis for battery packs,
2. generate synthetic data for heathy pack operation and for various degradation types and levels,

3. Use measurements and/or appropriate functions of the measurements to generate features that exhibit faulty/degraded behaviour,
4. Develop a classification method that decides on the pack state by processing the features extracted from regular measurements.

2.Combined electrochemical and machine learning based modelling of a battery cell including aging effects

Supervising team

Maxime Bussios and Michel Kinnaert, Maxime.Bussios@ulb.be, Michel.Kinnaert@ulb.be, SAAS, ULB

Context of the work:

Renewable energies and electric transportation are the cornerstones for developing a sustainable future society. Energy storage is fundamental in this context, in order to store surplus of energy and use it when the wind does not blow or the sun does not shine, or to produce vehicles that do not pollute the environment when they are on the roads.

Among the possibilities, lithium-ion batteries are the technology of choice given their high energy capacity and efficiency. However in contrast with other battery technologies, the benefits of lithium-ion batteries come at the price of careful monitoring requirements. Indeed, faulty cells in a battery pack can have catastrophic consequences including fire.

Objective of the thesis

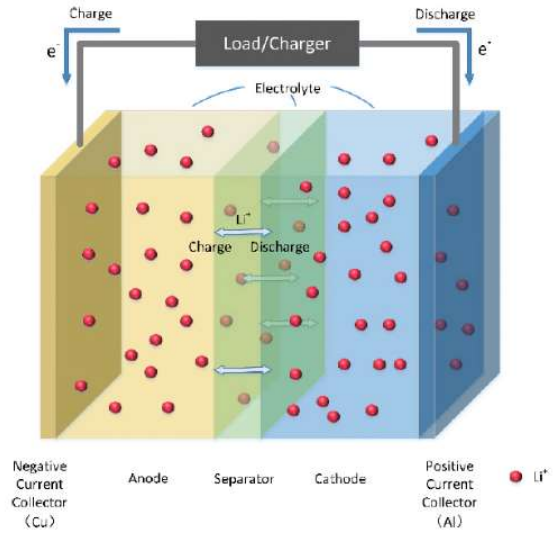
The objective of this thesis is to develop and compare different approaches to obtain a battery cell model that is sufficiently simple to be used in a battery monitoring system and yet provides an accurate and reliable estimation of the battery state of charge and state of health. Although simplified electrochemical or equivalent circuit models can provide reasonable state estimates, they do not typically account for aging. Several aging models have been determined from available data bases, but they are only valid[1]e for restricted battery operating conditions. As the modelling of aging mechanisms is extremely complicated, such models resort to machine learning methods. Combining physics based and data-based models yields to so-called hybrid battery models. The aim of this thesis is to improve hybrid battery models by accounting for a wide range of operating conditions and performing model update when a too large data to model distance is observed.

Both synthetic data obtained from a detailed battery simulator, to be modified to account for aging effects, as well as experimental data recorded on the SAAS battery testers and possibly other available data bases will be used.

Work to be done

The student should

1. perform a bibliographic search on battery cell modeling including aging modelling
2. generate synthetic data for heathy cell and for various degradation types under different operating conditions thanks to a detailed battery simulator, and analyze available experimental data.
3. select one or two promising structures for a hybrid model, develop a systematic methodology for estimating the model parameters, and validate it on the synthetic data
4. perform a validation of the method on experimental data



Schematic illustration of a lithium-ion battery

J. Zhang et al. “An Overview on Thermal Safety Issues of Lithium-ion Batteries for Electric Vehicle Application”. In: IEEE Access (May 2018), pp. 23848–23863. DOI: 10.1109/ACCESS.2018.2824838.

3.Combined data-driven and model-based monitoring of an electromechanical actuator for reusable launchers

Supervising team

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Context of the work

Europe is developing reusable launchers in the framework of different projects. To ensure launcher reliability, it is necessary to evaluate the state of health of the different parts of the launcher once it comes back to earth without dismantling it. The present project addresses the development of a systematic methodology to achieve this goal for the electromechanical actuators (EMAs) used to orientate the nozzle and the fins notably.

Objective of the thesis

State of health evaluation typically proceeds in two steps. First, fault indicators, also called residuals, are determined. These are signals that take small values in the absence of degradation and are reaching significantly non-zero values in the presence of certain faults. Next these fault indicators are processed through a decision system. The latter determines whether some of them are significantly different from zero and, if the answer is positive, attempts to isolate the fault(s), namely to indicate the faulty component(s) from the pattern of zero and nonzero residuals.

Due to modelling uncertainties, production variability and thermal effects notably, the border between healthy state and faulty state is not easy to set and machine learning techniques are useful tools to assign a healthy or a faulty class to a given data set. The performance of such methods often increases with the amount of data used for their training. In the considered case study, the amount of available data will increase with the number of launches, and it is thus worth being able to update the classifier regularly with new data sets.

The objective of this thesis is to compare some classifiers for this application and to investigate potential approaches for their update. The need for certification of the approach should be kept in mind, which means that interpretability of how the method operates is required.

Work to be done

The student should

1. perform a bibliographic search on automated feature determination in time series signals and classifiers
2. study the EMA models in healthy and faulty states and get acquainted with the simulator
3. process the residuals that will be provided to her/him in order to determine the most relevant features for fault detection/isolation
4. compare the most promising classifiers for this application in terms of performance and updating.

4.Design of new didactic devices for teaching of control engineering

(possibly 2 to 3 students)

Supervising team

Laurent Catoire (Laurent.Catoire@ulb.be), SAAS, ULB
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Context

Many of the pilot processes used in the SAAS department to teach control theory were developed through master's theses. This is the case for the rotary inverted pendulum, the ring positioner, the ball in the tube process, …

The aim of this master thesis is to develop new pilot processes that are modular, evolving, and open-source to provide a better and more practical learning experience to the students.

Here are a few examples of processes that SAAS would like to develop (non-exhaustive list):

- Ball in hoop or Flying ball in hoop
  - https://www.youtube.com/watch?v=8FaNk6C2ckM
  - https://www.youtube.com/watch?v=484GN4KBQnc
  - https://github.com/aa4cc/flying-ball-in-hoop
  - https://aa4cc.github.io/flying-ball-in-hoop/
- Cubli - robot that can jump up and balance on its corner
  - https://www.wevolver.com/specs/cubli
- …

Key objectives:

- selection of the sensors/actuators
- design of the signal conditioning / acquisition stages
- design of the experimental setup (SolidWorks, 3D printer …)
- design of the power supply & cable management
- modeling of the process
- implementation of a control strategy (Arduino/C programming or Matlab/data-acquisition board or Raspberry PI)
- setup of some didactic experiments & their related teaching materials

Requested skills:

- quick & autonomous learner in a dynamic environment
- team player, creativity
- basic knowledge in control theory, digital signal processing, electronics