Department of Control Engineering and System Analysis - SAAS

Master thesis proposals – academic year 2017-2018

1. Development of a Control System for Lithium-Ion Batteries

Supervisors: Raffaele Romagnoli, Alejandro Goldar, Michel Kinnaert and Emanuele Garone.

Despite the big efforts placed on the development of new battery technologies, a suitable control strategy embedded in a battery-management system (BMS) is required to make the operation of Li-ion batteries safe and durable. Moreover, such systems can ensure a proper battery operation in demanding scenarios like fast charging. This aspect represents a main challenge for the automotive industry linked to broad market acceptance of electric vehicles. Traditional BMSs are based on conservative control strategies such as constant current-constant voltage (CCCV) charging designed on equivalent circuit models (ECM). The new generation of BMS removes the conservativeness of those strategies by using electrochemical-based models (ECheM).

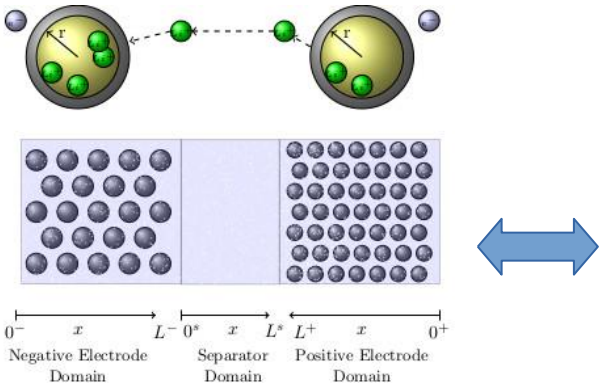


Figure a. Li-ion battery cell ECheM representation.

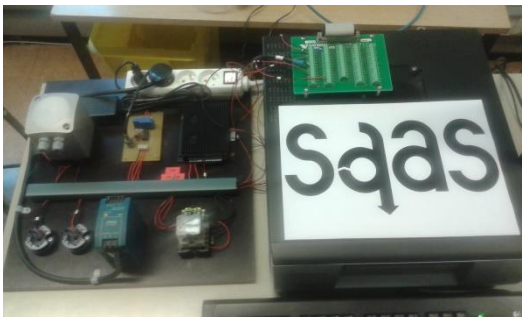


Figure b. Li-ion battery cell experimental setup.

The aim of this project is to design a controller based on a reduced-order ECheM (Figure a) to be both tested via simulation and validated via the experimental setup (Figure b). This task requires defining a suitable methodology in the simulation stage to handle possible implementation issues. The developed control law based on the reduced-order ECheM must satisfy the control requirements for the real Li-ion battery cell of the experimental setup.

Requirements: basic knowledge of Matlab; basic knowledge of control theory.

2. Optimal Battery Pack Topology and Sensor Placement

Supervisors: Alejandro Goldar, Luis D. Couto, Laurent Catoire and Michel Kinnaert

Context of the work

Recently, a great interest has been placed on renewable energies and electric transportation as cornerstones for the development of a sustainable future society. Both aspects require batteries to make them operationally profitable. Nevertheless, batteries are expensive and bulky since they are conservatively designed to ensure safety and longevity. Such conservatism can be avoided by using a *battery-management system* (BMS), which controls the battery in the most efficient way and makes it more affordable.

Figure 1 shows a battery pack representation (i.e. series/parallel arrangement of battery cells) along with its BMS. Linked to this representation, the goal of this project is twofold: one conceptual and one practical. Within the conceptual framework, simulation will provide insight of optimal battery pack topology and sensor placement. The criteria for topology selection (how the cells are connected in series/parallel) might be related with extending the battery lifetime. Once selected, the minimum number of available sensors (current, voltage and temperature) must be deployed throughout the battery pack to maximize state observability and/or fault detectability for instance.

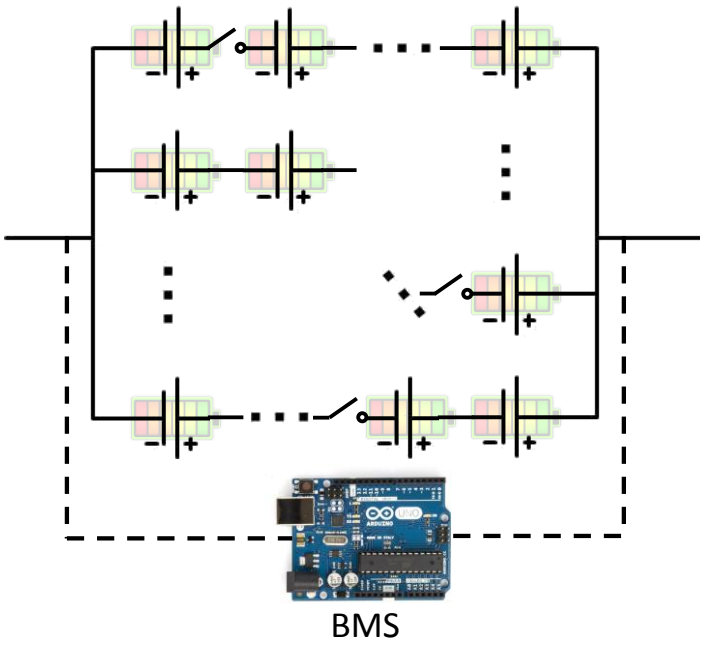


Figure 1 Battery pack comprised by series/parallel battery cells arrangement with a BMS monitoring/controlling the system.

Within the practical framework, an experimental test bench that resembles a typical battery pack will be built in the lab. Thus, the student has to evaluate the performance of the proposed topology and sensor placement in a real world scenario when compared with commercial approaches.

Requested skills

Basic knowledge in Matlab programing and control theory.

3. Data-based modelling and performance monitoring of the power grid

Supervisors:
Michel Kinnaert, SAAS, ULB (Michel.Kinnaert@ulb.ac.be)
Johnny Leung, SAAS, ULB (Johnny.Leung@ulb.ac.be)
Fortunato Villella, Elia

Context of the work

For almost one year, Elia has installed online high definition measurement systems, namely two mobile Phasor Measurement Units (PMUs), which are GPS-synchronized and have a resolution of 20 ms. The measurement campaigns were notably performed on some generators and power lines. The primary aim of this installation was to perform specific installations performance monitoring. Nevertheless, as a by-product, a large amount of data is now available for analysis.

Objective

The large amount of data should be analyzed in order to:

- Identify patterns in the data (oscillations, ...)
- Determine cross-interactions among the PMUs measured variables
- Perform model identification starting from available black-box models
- Perform model definition and identification of nonlinear behavior for some combination of loads and distributed generation units

Requested skills

Data analysis and processing, power systems, modelling and identification, MATLAB programming

***This master thesis can be combined with an internship at Elia**

4. Sensitivity of Power System Partitionings to Changes in Operating Conditions

Supervisors:
Michel Kinnaert, SAAS, ULB (Michel.Kinnaert@ulb.ac.be, 02-650.22.87)
Johnny Leung, SAAS, ULB (Johnny.Leung@ulb.ac.be, 02-650.26.13)

Context of the work

In the field of power system, several applications involve a partitioning phase of the electrical network.

- For defensive islanding, the network is subdivided into clusters that are potentially self-sufficient after an electrical fault.
- In the electricity market, partitioning techniques are used to identify groups of market participants (or generators) that have the ability to increase their own revenue, while the revenue of other participants remain constant.
- For network monitoring, the definition of clusters can help with the optimal placement of phasor measurement units (PMUs).
- And, in the context of model reduction, components with similar dynamic behaviors are grouped together before undergoing a reduction phase.

While the partitioning methods are different depending on the application, they all share a common objective: a power system partitioning should remain optimal after some changes in operating conditions. In general, a partitioning is obtained for one particular configuration of the electrical network, and there is no guarantee that it is still valid after, for instance, the outage of some lines or generators. For practical reasons, the composition of the clusters are rarely updated.

Given a general partitioning objective to be defined with the student, the purpose of this master thesis is to design a method for obtaining a partitioning that is relatively insensitive to arbitrary changes in operating conditions.

Work to be done

- Select a partitioning objective, and perform a bibliographical study on existing partitioning techniques for this particular objective
- Implement some of these techniques in Matlab on test models
- Define some variations in operating conditions, and analyze the sensitivity of the techniques that have been implemented
- Design a new method where the main focus is to obtain a partitioning, which is robust against changes in the electrical network, while satisfying the partitioning objective

Requested skills

Basic knowledge in power system, linear algebra, programming skills in Matlab

5. COLIBRI Robot - Design of manufacturing templates for the flapping mechanism

Supervisors:
Hussein Altartouri (Hussein.Altartouri@ulb.ac.be)
Emanuele Garone (egarone@ulb.ac.be)

The COLIBRI robot (Figure 1) is a flapping twin-wing robot of the size of hummingbird capable of hovering. The prototype has a total mass of 22 gr, a wing span of 21 cm and a flapping frequency of 22 Hz; it is actively stabilized in pitch and roll by changing the wing camber with a mechanism known as *wing twist modulation*.

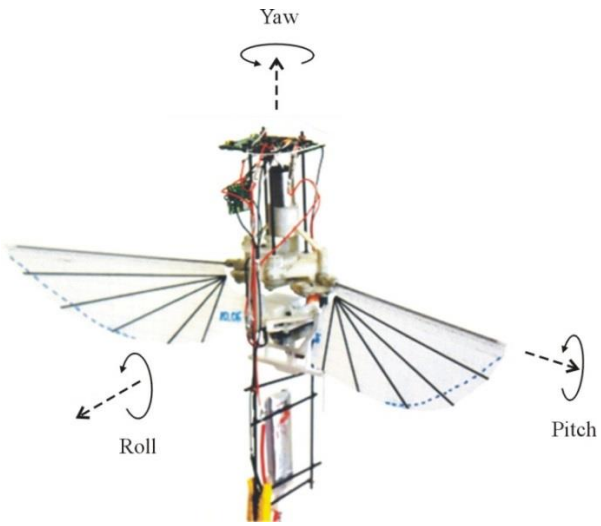


Figure 1: General view of the COLIBRI robot

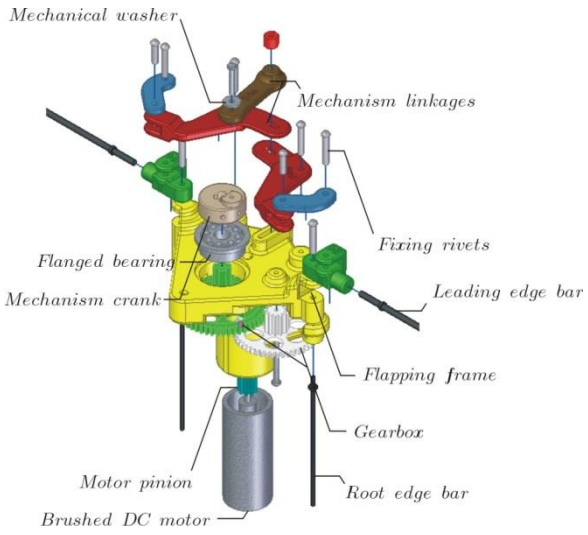


Figure 2: Exploded view of the flapping mechanism.

The goal of this project is to improve the manufacturing accuracy which is responsible for flapping asymmetry. The mechanism parts are obtained by 3D printing, the technology applied is selective laser sintering (SLS); the material is Nylon PA2200; the printing accuracy is $\pm 150 \mu m$, which is not sufficient for flapping the wings symmetrically. In order to improve the mechanism accuracy, a template will be designed then assembled with the mechanism for drilling some holes in it with an accuracy of $\pm 5\ \mu m$. Figure 2 shows an exploded view of the current flapping mechanism. After design and fabrication, the template would be tested on the mechanism by measuring the bias moments.

Requested knowledge: Mechanical design basics, CAD softwares (SolidEdge is preferred).

6. COLIBRI Robot - Yaw control

Supervisors:
Ali Roshanbin (Ali.Roshanbin@ulb.ac.be)
Emanuele Garone (egarone@ulb.ac.be)

The COLIBRI robot (Figure 1) is a flapping twin-wing robot of the size of hummingbird capable of hovering. The prototype has a total mass of 22 gr, a wing span of 21 cm and a flapping frequency of 22 Hz; it is actively stabilized in pitch and roll by changing the wing camber with a mechanism known as *wing twist modulation*.

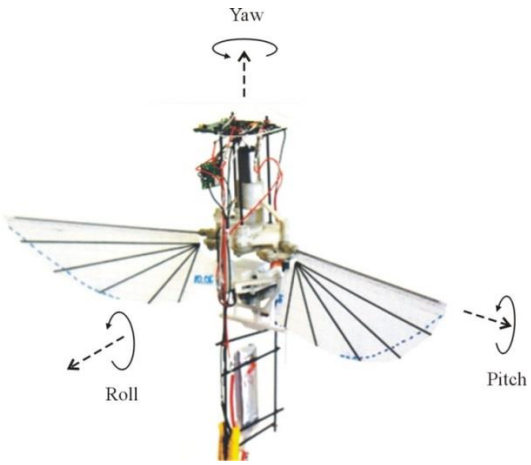


Figure 1: General view of the COLIBRI robot

Currently there is no control over yaw motion which is passively stable. However in order to control the robot attitude, developing a yaw actuation is indispensable. The robot is equipped with a flight controller providing the attitudes which can be used for yaw actuation command. In this project different types of actuation mechanisms suitable for controlling the bird's yaw motion will be explored and the conceptual designs will be developed. Also appropriate actuators for the different designs will be studied. The maximum weight of the proposed mechanisms should be less than 2 gr. The selected mechanism will be fabricated by the 3D printing technique after being designed in detail in order to integrate it to the robot. Then it will be assessed in terms of the control authority and coupling with pitch / roll moments and finally it will be evaluated with some flight experiments.

Requested skills: Solid edge software, Programming in C++ and familiar with Arduino and Mechatronics.

7. Constrained control of multirotors exchanging forces with the environment

Supervisors:

Emanuele Garone (egarone@ulb.ac.be)

Tam Nguyen

Goal

The goal of this master thesis is to develop control schemes for multirotors interacting in force with the environment and subject to constraints (physical constraints and saturation). The thesis may foresee experimental activities, depending on the availability of the laboratory. The details of the project should be discussed with the professor and tuned depending on the background of the student.

Prerequisites: Control System design course.

8. Validation and control of a test-bench for the study of bi-stable beams.

Supervisors:

Laurent Catoire

Emanuele Garone

Context of the work

The project concerns the identification of the parameters, the validation of the model and the control of a well-known multistable structure: the bi-stable buckled beam. The beam is subjected to end-shortening conditions which cause the buckling.

Two motors are placed at both ends of the beam and apply a torque on the extremities. This may cause the snapping of the structure. The transition between two stable states will be studied and tried to be planned. The dynamic of the transition will be studied as shown in the figure.

Description of the work

In this project the student will be asked to complete the experimental validation of the dynamic model of the system already developed in a previously developed master thesis and to perform experiments to prove the effectiveness of some proposed control laws included

- PD + elasticity compensation / PID + elasticity compensation
- Induction of vibration
- Nonlinear set-based Reference Governor

Requested skills

- Knowledge of mechanical modelling
- Control System Design

9. Reference Governor: the design of strongly returnable sets

Supervisor : Emanuele Garone

Goal

The idea of this thesis is to investigate the idea of Strong Returnability introduced by I. Kolmanovsky in his general nonlinear reference governor. Strong Returnability is a weaker form of invariance that comes back in several constrained control problems. The goal of this thesis will be to devise (possibly automatic) methods to determine Strong Returnable set and to apply the devised method on some technological plant

Prerequisites: Control System design course.

10. Design and development of a demonstrator for a wind turbine condition monitoring system (possibly for two students)

Supervisors:

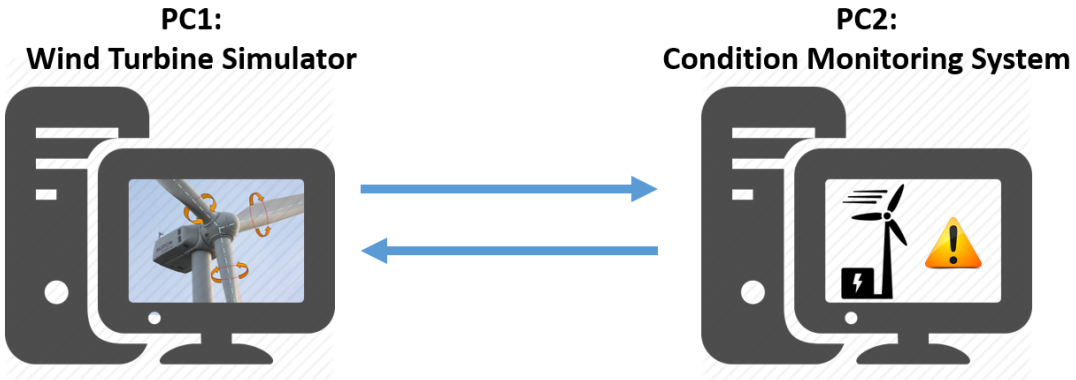
Sandra Vásquez, SAAS, ULB (savasque@ulb.ac.be)
Michel Kinnaert, SAAS, ULB (Michel.Kinnaert@ulb.ac.be)

Context

A condition monitoring system aims at early detection and localization of malfunctions within the different components of a wind turbine. An early warning allows one to perform maintenance operations in due time and during low wind periods in order to avoid production losses. Such a condition monitoring system has been under development at the SAAS. To validate this system, one uses both actual data recorded on wind farms in Europe, as well as synthetic data generated by a wind turbine simulator. For the moment it is indeed not possible to obtain well documented data for the different faulty modes, hence the need to resort to a simulator.

Objective of the master thesis

The objective is to develop a demonstration platform made of two software tools running on two PC's interacting with each other. The first PC (PC1) should run the wind turbine simulator, where the data acquisition system available in most wind turbines (i.e. the SCADA system) will be emulated in order to generate synthetic data. Both normal and faulty operating modes will be considered. The second PC (PC2) should run the condition monitoring system able to process on-line the synthetic data and issue a diagnosis on the state of health of the different wind turbine components (sensors, actuators, etc.).



- **PC1: wind turbine simulator**
  The available wind turbine simulator runs in the MATLAB/SIMULINK environment, and it is based on the FAST software developed by the National Renewable Energy Laboratory (NREL, USA). The aim of the thesis is to introduce additional faulty scenarios in the simulator and to develop a friendly user interface for this simulator, starting from the work that has been done previously on this interface. The simulation of the data acquisition system and the communication interface with the PC2 should also be developed.

- **PC2: condition monitoring system**
  Different methods have been developed for the monitoring of individual sensors, redundant sensors, the pitch system and the global wind turbine performance. These methods have been validated independently. To complete this work, the following tasks are required:

  - the interplay between the different software modules implementing the above mentioned methods should be studied;
  - how best to group the outputs of the different modules to end up with a global diagnostic solution is also an open issue;
  - the on-line implementation has only been considered for some of the methods.

  The aim of the thesis is thus to design and validate, on the basis of synthetic data and actual SCADA data, a library of easily configurable software modules suitable for the implementation of an on-line condition monitoring system. The MATLAB/SIMULINK environment will be used for the software development. The library will be exploited to design a demonstrator of wind turbine condition monitoring adapted to the wind turbine simulator.

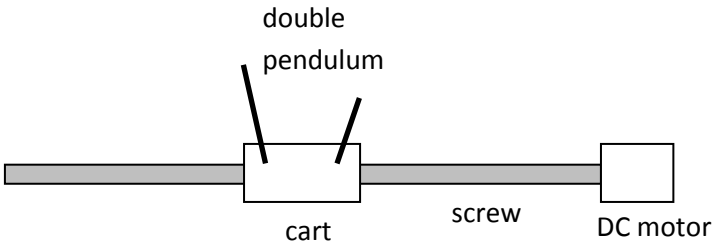
11. Digital control of a self-erecting double inverted pendulum

Supervisors:

Laurent Catoire (laurent.catoire@ulb.ac.be)
Michel Kinnaert (michel.kinnaert@ulb.ac.be)

Description

The double inverted pendulum of our laboratory is composed of a screw driven cart on which the pendulum is connected. The cart position is controlled by a direct current motor. A simplified scheme of the process is the following:



Different sensors are available to measure: the position of the cart and the angles of the two pendulum poles.

The control objective is to take the pendulum from its stable position to the upright position by moving the cart.

Phases of the project

- Study of the process, familiarization with the existing simulator, validation of its parameters.
- Bibliographical study on inverted pendulum control
- Pendulum sizing (length of the poles)
- Design of different control laws
- Validation and comparison of the control laws in simulation
- Validation on the real process.