Seminar 2024

Health Aware and Safe Control Learning & Design for Dynamic Systems

November 19th, 2024,
ENSAM
Le Cnam – Paris

Sponsored by GDR MACS

The seminar presents an opportunity to foster exchanges and identify possible synergies and joint works. This year, the seminar will be held **on November 19th, 2024 from 9h30 to 17h at**

Amphi A - Ensam, Le Cnam
Arts et Métiers, Ensam, Paris
151, boulevard de l'Hôpital, 75013, Paris

Registration is mandatory **and** free (Lunch and coffee break are not included) – **Please click on the link to register:**

LINK FOR REGISTERATION (OBLIGATORY)

Seminar Pre – Program (Temporary)

9h45 – 10h45 Title: *From Ageing-Aware Battery Discharge Prediction to Optimal Health-Aware Operation*
Presenter: Dr. Olga Fink, Assistant Professor, Intelligent Maintenance and Operations Systems, **École Polytechnique Fédérale de Lausanne (Swiss Federal Institute of Technology Lausanne),** EPFL ENAC IIC IMOS, **Lausanne.**

10h45-11h30: *Reinforcement Learning based Degradation-Tolerant Control Design for Affine Nonlinear Systems.*
Presenter, Co-Authors**: Soha Kanso**, Dr. Mayank Jha, Prof. Didier Theilliol, CRAN, University of Lorraine, **France.**

11h30-12h30: *Health-Aware predictive maintenance planning for complex systems*
Presenter: Dr. Mihaela Mitici, Assistant Professor, Utrecht University, **the Netherlands.**

Lunch

14h00 - 15H00 – Title: Title: *Degradation-Aware Model Predictive Control For Marine Solid-Oxide Fuel Cells*
Presenter, Co-Authors: **A. Caspani,** Dr. V. Reppa, Dr. R.R. Negenborn
Department of Maritime and Transport Technology, Faculty of Mechanical Engineering, Delft University of Technology, Mekelweg 2, 2628 CD Delft, **The Netherlands**.

15h00 - 16h00 – Title: *A Degradation Parameter Observer for State of Health (SoH) Assessment of Lithium-Ion Batteries*
Presenter, Co-Authors: **M. S. Félix**, Prof. J. J. Martinez, Prof. C. Bérenguer
Université Grenoble Alpes, CNRS, Grenoble INP, GIPSA-Lab, Grenoble, **France**

16h00-16h45: *Advancements in Unsupervised Deep Learning based Prognostics*
Presenter: Dr. Mayank Jha, CRAN, University of Lorraine, **France.**

This seminar is sponsored by GDR MACS as a specific action led by:

Dr. Mayank S Jha
Pr. J. J. Martinez Molina,
Pr. Didier Theillol,
Pr. Philippe Weber and,
Pr. Christophe Berenguer

See the link for more details and 2023 Seminar.
http://w3.cran.univ-lorraine.fr/mayank-shekhar.jha/?q=content/health-aware-and-safe-control-design-gdr-macs-action).

Abstracts

9h45 – 10h45 Title: *From Ageing-Aware Battery Discharge Prediction to Optimal Health-Aware Operation*

Presenter: Dr. Olga Fink, Assistant Professor, Intelligent Maintenance and Operations Systems, **École Polytechnique Fédérale de Lausanne (Swiss Federal Institute of Technology Lausanne),** EPFL ENAC IIC IMOS, **Lausanne.**

Abstract: Abstract: In this talk, we will introduce Dynaformer, a novel deep learning architecture designed to infer the ageing state from limited voltage/current samples and accurately predict the full voltage discharge curve. Our evaluation demonstrates that Dynaformer performs well on simulated data and, with minimal fine-tuning, effectively bridges the gap to real-world battery data. This methodology enables controlled and predictable battery usage until end-of-discharge, extending operating cycles and reducing costs.

Building upon these health-aware discharge predictions, we will address the joint problem of mission planning and health-aware real-time control of operational parameters. We will present a deep reinforcement learning algorithm that proactively prescribes operational parameters to extend the discharge cycle based on the battery's current health status while optimizing the mission. Evaluation using simulated flights of a NASA conceptual multirotor aircraft model, gathered from Hardware-in-the-loop experiments, demonstrates the algorithm's near-optimal performance across various operational scenarios, allowing adaptation to changing environmental conditions.

10h45-11h30: *Reinforcement Learning based Degradation-Tolerant Control Design for Affine Nonlinear Systems.*

Presenter, Co-Authors**: Soha Kanso**, Dr. Mayank Jha, Prof. Didier Theilliol, CRAN, University of Lorraine, **France.**

Abstract: The functional degradation of components in dynamical systems presents a critical challenge to both performance and stability, potentially leading to system failures or compromised safety. This talk focuses specifically on actuator degradation and introduces a novel degradation-tolerant controller based on reinforcement learning, designed for continuous-time nonlinear systems affine in control input. The primary objectives are twofold: firstly, to ensure system stability despite ongoing degradation, and secondly, to decelerate the degradation rate to ensure mission completion and possibly extend the remaining useful life of the actuators. To achieve this, constraints are imposed on the degradation rate using control barrier functions. Additionally, a novel algorithm termed cyclic off-policy is presented, enabling iterative exploration and exploitation across multiple learning cycles. This approach allows for cyclic updates of neural network weights with recent information on the degradation level, ensuring that the learned policy effectively stabilizes the system while efficiently accounting for the effects of degradation. The effectiveness of the proposed degradation-tolerant control approach is validated through simulation results on both an academic nonlinear system and an inverted pendulum cart model, demonstrating the approach's efficiency in addressing actuator degradation.

11h30-12h15: *Health-Aware predictive maintenance planning for complex systems*

Presenter: Dr. Mihaela Mitici, Assistant Professor, Utrecht University, **the Netherlands.**

Abstract: Complex systems such as wind turbines, Lithium-ion batteries, aircraft engines are continuously monitored by sensors. Wind turbines, for example, are equipped with in-built Supervisory Control and Data Acquisition (SCADA) systems that record hundreds of parameters. With these, predictions on the health condition of the wind turbines are developed, and maintenance strategies are designed. In this presentation I will discuss current advances on the integration of data-driven prognostics into health-aware maintenance planning models. For the case of wind turbines and batteries, I will discuss how data-driven Remaining Useful Life prognostics can be efficiently used to optimize the moment of inspection and battery replacement, respectively. In both cases, model-based approaches for the maintenance planning are proposed. For aircraft engines, I will discuss the use of a model-free approach (reinforcement learning) to plan maintenance based on data-driven prognostics. Overall, this presentation illustrates effective planning approaches for maintenance taking into account health estimates of complex systems.

14h00 - 15H00 – Title: Title: *Degradation-Aware Model Predictive Control For Marine Solid-Oxide Fuel Cells*

Presenter, Co-Authors**: A. Caspani,** Dr. V. Reppa, Dr. R.R. Negenborn
Department of Maritime and Transport Technology, Faculty of Mechanical Engineering, Delft University of Technology, Mekelweg 2, 2628 CD Delft, **The Netherlands**.

Abstract: Solid Oxide Fuel Cells (SOFCs) represent a promising technology in the field of electric power generation, particularly suited for alternative (low emission) fuels and for large scale applications. With the marine industry accounting for 3% of the global greenhouse gas emissions, and the current International Maritime Organization (IMO) guidelines aim for complete a full decarbonisation by year 2050, there are significant efforts to introduce SOFCs on a large scale in maritime applications. However, due to their intrinsic properties, SOFCs still suffer from limited dynamic performance and internal deterioration. Therefore, effective deployment in marine applications will require further improvements in reliability, resistance to cell degradation and, consequently, extended lifetime. In this context, we propose a Degradation-Aware control (DAC) strategy for SOFCs, designed for marine applications, integrating direct limitation of cell voltage degradation. First, we introduce the enlarged state space model comprising a reduced order model of SOFC dynamics (SOFC-ROM) and the voltage degradation model of the cell. Secondly, we develop the DAC using a nonlinear Model Predictive Controller (nMPC), which optimizes performance and manages degradation effectively. Simulations were carried out, incorporating realistic constraints and performance metrics, to evaluate the impact of the proposed control strategy under varying load demands. The results demonstrate the ability of the proposed strategy to limit SOFC voltage degradation while ensuring the required dynamic response of the cell's power output.

15h00 - 16h00 – Title: *A Degradation Parameter Observer for State of Health (SoH) Assessment of Lithium-Ion Batteries*

Presenter, Co-Authors**: M. S. Félix**, Prof. J. J. Martinez, Prof. C. Bérenguer
Université Grenoble Alpes, CNRS, Grenoble INP, GIPSA-Lab, Grenoble, **France**

Abstract: For effective health management in Lithium-ion (Li-ion) battery-powered applications, accurately estimating the batteries' State-of-Health (SoH) is often a critical first step. We propose a method that assesses the level of degradation in Li-ion batteries using a novel dynamic model for battery charging and discharging, as initially introduced in [1], along with a robust state observer design. This approach can effectively track changes in battery electrical behavior resulting from degradation and estimate degradation dynamics, as demonstrated through simulated and experimental data [2]. A case study within a battery-powered scenario will illustrate the practical usefulness of this approach for health management strategies.

[1] Martinez, J. J., Félix, M. S., Kulkarni, C., Orchard, M., & Bérenguer, C. (2024). A novel dynamical model for diagnosis, prognosis and health-aware control of Lithium-ion batteries. *IFAC-PapersOnLine*, *58*(4), 658-663.
[2] Fricke, K., Nascimento, R., Corbetta, M., Kulkarni, C., & Viana, F. “Accelerated Battery Life Testing Dataset”, NASA Prognostics Data Repository, Probabilistic Mechanics Lab, University of Central Florida, and NASA Ames Research Center, Moffett Field, CA

16h00-17h00: *Advancements in Unsupervised Deep Learning based Prognostics*

Presenter: Dr. Mayank Jha, CRAN, University of Lorraine, **France.**

Abstract: In many industrial contexts, the presence of multiple failure trajectories and the lack of true RUL labels pose significant challenges. This limitation has led to a growing interest in unsupervised learning methods for prognostics, which aim to predict RUL without relying on labeled data. This presentation will introduce the fundamentals of artificial intelligence (AI), CNNs, and LSTMs, and how they have been traditionally applied to the prognostics problem in a supervised manner. Following this, we will explore the motivation and need for unsupervised prognostics, especially in industrial environments where labeled RUL data is scarce. The latest advancements in unsupervised deep learning techniques will be highlighted, focusing on innovative approaches that leverage unlabeled data to predict RUL. These cutting-edge methods have been developed in collaboration with leading industrial partners, such as Dassault Aviation, and have been validated through real-world case studies.

[1] de Beaulieu, Martin Hervé, Mayank Shekhar Jha, Hugues Garnier, and Farid Cerbah. "Remaining Useful Life prediction based on physics-informed data augmentation." *Reliability Engineering & System Safety* 252 (2024): 110451.
[2] De Beaulieu, M. H., Jha, M. S., Garnier, H., & Cerbah, F. (2022, July). Unsupervised remaining useful life estimation based on deep virtual health index prediction. In *7th European Conference of the Prognostics and Health Management Society, PHME22*.