Seminar on Health Aware and Safe Control Design for Dynamic Systems
November 22nd, 2023, Ensam, Le Cnam - Paris
Sponsored by GDR MACS

This seminar is sponsored by GDR MACS in a specific action (with duration of two years, see the link https://gdr-macs.cnrs.fr/node/4286) and is an opportunity to foster exchanges and identify possible synergies and joint works.The seminar will be on November 22th, 2023 from 9h 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:**

LINK

No registration No seminar

Seminar Pre – Program

10H - 11h – Title: Health-aware control of complex industrial systems - **Author(s):** Prof. V. Puig
Institut de Robòtica i Informàtica Industrial, CSIC-UPC
C/ Llorens i Artigas 4-6, 08028, Barcelona, Spain

11H - 11h45 – Title: HUMANS Research Project – Health and Usage Monitoring for Aerospace Next-generation Systems - **Author(s):** Elinirina Robinson, Florian Dietrich, Ioannis Sarras
Département traitement de l'information et systèmes
NGPA (Navigation Guidage Pilotage de véhicules Autonomes)
ONERA - The French Aerospace Lab - Centre de Palaiseau
6, Chemin de la Vauve aux Granges - 91123 PALAISEAU

11h 45 - 12h30 – Title: Controlling the remaining useful life of a wind turbine flexible drive-train. - **Author(s):** M. S. Félix, J. J. Martinez, C. Bérenguer
Université Grenoble Alpes, CNRS, Grenoble INP, GIPSA-Lab, Grenoble, France
11, rue des Mathematiques - BP46
38402 Saint Martin d'Hères cedex – France

14h00 - 14H45 – Title: From a current industrial practice in biomedical engineering to a generic health-aware supervisory control framework - **Author(s):** Pr. J. Cieslak
IMS Lab. UMR CNRS 5218 - Dpt. P3S – Automatic Control Group
Université de Bordeaux, Bât A31-B, IMS Lab. - Dpt P3S
351, cours de la libération, 33405 Talence Cedex, France

14H45 - 15h30 – Title: Remaining useful life prognosis of a deteriorating feedback control system and application to controller reconfiguration
- **Author(s):** Y. Gong, T.K. Huynh, Y. Langeron, A. Grall
LIST3N - Université of Technologie de Troyes, 12 rue Marie Curie - CS 42060. 10004 Troyes cedex – France

15h30 - 16h15 - Title: Prognostics aware control design: Application to Liquid Propellant Reusable Rocket Engine and Recent Advances in Safe Control Learning
Author(s): J. Thuillier(*), M.S. Jha(+), S. Le Martelot (*), D. Theilliol(+)
(+) CRAN UMR 7039, CNRS - Faculté des Sciences et Technologies - B.P. 70239
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Abstracts

10H - 11h – Title: Health-aware control of complex industrial systems

Author(s): Prof. V. Puig
Institut de Robòtica i Informàtica Industrial, CSIC-UPC
C/ Llorens i Artigas 4-6, 08028, Barcelona, Spain

Abstract: This talk will present a framework to address the health-aware control based on model predictive control (MPC). The MPC controller will include in the control model the model of system health and in the objective function an additional term to maximize the remaining useful life. Several real case studies will be presented to illustrate the proposed approach.

11H - 11h45 – Title: HUMANS Research Project – Health and Usage Monitoring for Aerospace Next-generation Systems

Author(s): Elinirina Robinson, Florian Dietrich, Ioannis Sarras
Département traitement de l'information et systèmes
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Abstract: This research project focuses on the development and simulation of a generic advanced monitoring architecture to ensure the safety and optimise the maintenance of complex aeronautical and aerospace systems. This monitoring architecture will include a module for monitoring the state of health of the system (diagnosis and prognosis), and a mission reconfiguration module. This reconfiguration module will consist of two distinct parts: fault-tolerant control and trajectory reconfiguration. Fault-tolerant control will enable the system to continue operating in degraded conditions if a fault occurs on one or more of the engines. If the state of the system no longer allows the given mission objective to be pursued, trajectory reconfiguration will then be necessary. To do this, methods for generating trajectories under uncertainty will be developed so that a set of possible trajectories can be determined off-line if the system is unable to continue its mission. On-line selection of the optimal trajectory to follow will be subject to constraints on system performance and available resources. The system monitoring architecture proposed in this project will be built from various algorithmic building blocks whose development has already been the subject of research work in theses and projects previously carried out at ONERA. The aim is to improve, adapt and link together these different algorithmic building blocks in order to build a generic supervision architecture that will enhance safety and optimise the maintenance of the systems that will be equipped with it.

11h 45 - 12h30 – Title: Controlling the remaining useful life of a wind turbine flexible drive-train.

Author(s): M. S. Félix, J. J. Martinez, C. Bérenguer
Université Grenoble Alpes, CNRS, Grenoble INP, GIPSA-Lab, Grenoble, France
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Abstract: We propose a degradation-aware control approach that allows to control the remaining useful life of a deteriorating wind turbine system. We consider more particularly the degradation caused by torsion effects in the drive-train, and we aim at controlling it by acting on the control gain of the generator torque. The proposed approach includes an observer-based control structure for solving this degradation control problem. By applying well-know control design techniques, such as optimal state-feedback control, the degradation process can be controlled while guaranteeing the stability of the wind turbine system. A numerical case study illustrates the advantages of the proposed approach for controlling degradation of a 4.8MW wind turbine drive-train, allowing to extend its remaining useful life.

14h00 - 14H45 – Title: From a current industrial practice in biomedical engineering to a generic health-aware supervisory control framework

Author(s): Pr. J. CIESLAK
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Abstract: Type 1 diabetes (T1D) is a major disease linked to the destruction of pancreatic β-cells, resulting in an absolute deficiency of insulin, the only hormone reducing blood sugar level. To provide safe care for T1D patients, the development of automated insulin delivery (AID) technologies dedicated to glycaemic regulation becomes of great interest. Among algorithms in AID system, one is dedicated to switch off AID in response to predicted low sensor glucose (SG) values (''suspend before low''), suspension in response to existing low SG values (''suspend on low''), and automatic restarting of basal insulin delivery upon SG recovery. To be able to offer some theoretical guarantees in this closed-loop therapy centered on the human, this talk introduces a preliminary framework of a Hybrid Health-Aware Supervisory Control (HHASC) scheme for Linear Time Invariant (LTI) systems. The proposed HHASC setup integrates a switching controller, a supervisory able to identify the operating mode and the use of a deterministic prognostic information. To highlight the generic nature of the approach, the problem statement will be formulated in a Fault Tolerant Control (FTC) context, i.e proposed solution is able to manage current and future faulty situations to extend the remaining system life by the consideration of control objective mitigations. In addition, the introduction of the Prognostic Decision-Making (PDM) unit fitted with a Virtual Fault Mechanism (VFM) allows to forecast the switching FTC and reduce the reconfiguration transients. The dwell-time property and its dual part are used to derive a closed-loop stability proof. The proposed HHASC framework provides then a cohesive setup where prognostic, diagnosis and accommodation tasks can work in harmony together. To highlight its genericity, the proposed solution is finally applied on a numerical aeronautical benchmark.

14H45 - 15h30 – Title: Remaining useful life prognosis of a deteriorating feedback control system and application to controller reconfiguration

Author(s): Y. Gong, T.K. Huynh, Y. Langeron, A. Grall
LIST3N - Université of Technologie de Troyes, 12 rue Marie Curie - CS 42060. 10004 Troyes cedex – France

Abstract: The feedback control system is vital for modern automatic control, finding applications across diverse fields. Its fundamental concept involves comparing the observed output with a target value to result in an error. This error is then utilized as input of the feedback controller to drive the system output towards the target. However, irrespective of the quality of controller design, the inner system inevitably experiences unobservable stochastic damage over time, due to usage and external disturbances. The accumulated damage of critical components, ultimately leads to the failure of the entire feedback control system. Our objective is to develop a method to predict the remaining useful life of the deteriorating feedback control system, facilitating its online application such as controller reconfiguration.
In our work, we assume the physical knowledge of the feedback control system is unknown. To predict its remaining useful life, two issues should be addressed: *i*) monitoring the degradation of entire feedback control system only through observable reference input and output data; *ii*) mitigating the impact of fault-tolerant controller on degradation monitoring. To tackle the above issues, a low-efficiency controller is deployed in the deteriorating feedback control system to mitigate the control impacts on degradation information. Consequently, the switching from the original controller to the inefficient one at each inspection time, allows unveiling more information about internal damage through reference input and output data. To construct a degradation index from the above collected reference input and output data, we solicit the feedback control system with low-efficiency controller by a unit step reference input signal, and define the peak value of the associated output response as the degradation index. In order to predict the remaining useful life, we first apply stochastic diffusion process with nonlinear drift and diffusion to model the degradation index evolution. Deriving the distribution of remaining useful life directly through probability calculation based on the index model proves challenging. Therefore, we address this complexity by transforming the stochastic diffusion process into a standard Brownian motion, and subsequently approximate the cumulative distribution of the first time that the standard Brownian motion hits the transformed failure boundary. During the above procedures, two transforms and a drift approximation method are utilized respectively to benefit the process transformation. Meanwhile, tangent boundary approach also favors the distribution approximation.

To show the usefulness of the developed remaining useful life prognosis method, we apply it to controller reconfiguration. We examine a fixed-duration mission during which the entire feedback control system naturally undergoes degradation. Normally, the mission could be accomplished before the system fails. However, external environmental factors may randomly introduce additional stresses during the mission, and lead to random jumps in degradation at unpredictable moments. The accident hinders the completion of the mission within the designated timeframe. Our idea is to reconfigure the controller whenever an accident occurs to enhance the probability of completing the mission within the specified time. This action requires considering the performance of feedback control system (i.e., mission completion) in relation to the remaining useful time. In order to strike a balance between system performance and its remaining useful life, we use the steady-state error between the feedback control system output and reference input as a measure of system performance. Through the combination of this error with the remaining useful life distribution of feedback control system, an objective function is formulated. The optimization process involves selecting the controller intensity that minimizes this function.

15h30 - 16h15 - Title: Prognostics aware control design for extended remaining useful life: Application to Liquid Propellant Reusable Rocket Engine and Recent Advances in Safe Control Learning

Author(s): J. Thuillier(*), M.S. Jha(+), S. Le Martelot (*), D. Theilliol(+)
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Abstract: As most of the safety critical industrial systems remain sensitive to functional degradation and operate under closed loop, it becomes imperative to take into account the state of health within the control design process. To that end, an effective assessment and extension of the Remaining Useful Life (RUL) of complex systems is a standing challenge that seeks novel solutions at the cross-over of Prognostics and Health Management (PHM) domain as well as automatic control. This paper considers a dynamical system subjected to functional degradation presents a novel control design strategy. Wherein the assessment of state of health of the system is taken into account leading to effective prediction of the RUL as well as its extension. To that end, the degradation model is considered unknown but input-dependent. The control design is formulated as an optimization problem wherein a suitable comprise is reached between the performance and desired RUL of the system. The main contribution of the paper remains in proposal of set-point modulation based approach wherein the control input at a given present time stage is modulated in such way that futuristic health of the system over a long time horizon is extended whilst assuring acceptable performance. The effectiveness of the proposed strategy is assessed in simulation using a numerical example as well as liquid propellant rocket engine case.