Model-based prognostics and degradation tolerant control for aerospace vehicles

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Topic description

Prognostics allows predicting the Remaining Useful Life (RUL) time beyond which the system can no longer be used to meet desired performance. To make the prognostics of a system, it is necessary to estimate system's current state and then project it into the future to estimate system's RUL at each time instant. There are three main approaches to achieve these tasks: knowledge-based approaches (the use of information acquired from experts and fault records on a system), data-driven approaches (learning directly from data characteristics to assess the health status of a system), model-based approaches (the comparison between the actual functioning of a system and its reference mathematical model constructed from laws of physics). We focus on this last one.

The model-based prognostics is composed of two main steps: (i) estimation of the current degradation state and (ii) prediction of its future state. The first step, filtering, is done from model and available measures. The second step consists of uncertainty propagation methods. The main challenge of prognostics concerns to take into account the different sources of uncertainties for obtaining a measure of the uncertainty associated to the RUL predicted. To manage these uncertainties and integrate them into the prognostics, probabilistic methods as well as set-membership methods have been developed in a PhD thesis defended in 2018. A particle filtering algorithm has been applied on real data for the prediction of fatigue crack growth in structural elements made of unidirectional fiber-reinforced composites [1], implemented to detect abrupt load variations [3]. A new filtering algorithm and prediction from a modeling of uncertainties in the form of intervals have been also developed for linear time-invariant discrete-time systems, taking into account unknown inputs [2].

Inspired by these results, the first objective of this postdoc is to develop new estimation and uncertainty propagation methods based on the concepts of set-membership estimation, it's about, in particular, developing a set-membership observer (interval observer [4] or zonotope observer [5]) applicable to discrete-time nonlinear systems for diagnosis and prognostics. The second objective of this postdoc is to design fault and degradation tolerant control. It's about, in particular, ensuring the success of a given mission considering the RUL of the components and the retroactivity impact of the control solicitations on these elements (especially in the context of the navigation of autonomous aerospace vehicles such as launchers or drones). The Fault Tolerant Control is very actively studied [6], especially from an "active" point of view where a diagnostic module provides an estimate of the fault, which is then explicitly compensated by the control law to continue the operation of the system. This approach therefore makes it possible to react immediately to a fault, but not to anticipate its evolution and its consequences on the system.

The developed control methods can base on the predictive control, especially in its robust versions, which naturally propagates a dynamic system model and updates the information on the environment at each instant. Another approach generally used in robotics or aerospace field is to generate a trajectory considering the dynamics of the vehicle and the constraints on the state and the control, then tracking this trajectory with a simpler control (which can be linear predictive control for example). We will study taking into account degradation and estimated residual lifetime (especially with previously developed set-membership techniques) in the context of these different approaches, in order to achieve an approach applicable to different types of vehicles (launchers, long-endurance drones, transport aircraft).

References

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