PhD thesis proposal, CSC 2021

Title: Machine Learning for Predictive Maintenance of Deteriorating Dynamic Systems

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Keywords: Dynamic systems; Machine learning; Predictive maintenance; Prognosis; Stochastic modeling.

Description:

Motivation

Systems are dynamic if their time-dependent behavior can be expressed in the form of a differential equation, or more generally in a state-space representation. Such systems cover a wide range of applications in the world of industry, as well as on a daily basis. We can enumerate, for instance, CNC machine tools in manufacturing industry, or aircraft undercarriage, control surfaces, level crossing actuators in aeronautical and railway sectors, etc. With usage, age and environment impacts, dynamic systems suffer gradual degradation and eventually random failures, which can lead to catastrophic damage to industry and society. Keeping the efficient operation of dynamic systems at a high reliability is thus vital to enterprises, especially in the context of aggressive global competition.

Predictive maintenance could be an appropriate solution to enterprises that seek a competitive advantage. Within predictive maintenance framework, the future health state of system is predicted in real-time using collected condition monitoring data, and through that knowledge, maintenance decisions are made [1]. In the current state of the art, stochastic modeling of system degradation and failure is the heart of these tasks. It concerns about the choice of a suitable stochastic process within the family of Lévy processes or diffusion processes that best fits given degradation and failure data [2]. However, such a choice is not always straightforward because it depends on various factors such as the system nature (single-unit or multi-unit, centralized or distributed), the nature of degradation phenomenon (monotonic or fluctuant, homogeneous or heterogeneous), the available information about the system state (degradation data and/or failure data), and the applied maintenance policy (static or dynamic). This obstacle is even more serious for dynamic systems that usually made up of a combination of components with different technologies and structural, stochastic and economic dependencies among them. It is thus crucial to develop new tools to support the degradation modeling, hence the prognosis and predictive maintenance decisions for deteriorating dynamic systems.

Machine learning, within artificial intelligence, has emerged as a powerful tool for developing intelligent predictive algorithms in many applications. In particular, it has the ability to handle high dimensional data with

various nature, and to extract hidden relationships within data in complex and dynamic environments. Therefore, machine learning, along with the availability of vast amounts of degradation and maintenance data in near real-time, is expected to be a new and promising paradigm in designing and performing predictive maintenance for dynamic deteriorating systems. Nevertheless, how to apply concretely machine learning approaches into predictive maintenance modeling is still an open and challenging issue for both industry and academia [3].

General layout of the thesis

The focus of this Ph.D. thesis is not on developing new and sophisticated machine learning algorithms, but rather on inheriting the recent development of machine learning to explore how artificial intelligence can be a lever to improve predictive maintenance performances of deteriorating dynamic systems. Indeed, while the former has a long literature, the latter is rather new and crucial for current practical needs. Our ambition is to investigate the added value of machine learning at all levels of a predictive maintenance program (from deterioration modeling to prognosis, and toward maintenance decision making) depending on the availability of degradation and maintenance data.

The main steps of this Ph.D. thesis are summarized as follows.

1. *Stochastic simulator development*. The simulator allows to generate data for dynamics systems subject to a given predictive maintenance policy. These data are inputs of the next steps.
2. *Degradation modeling*. This step aims to build a stochastic model describing properly the degradation phenomenon of dynamics systems. Machine learning techniques will be used to extract degradation features of the system, and hence synthetize a health state indicator. They also contribute in the identification of a suitable degradation model for the system.
3. *Prognosis.* This step focuses on the estimation of the remaining useful time (RUL) of dynamics systems. We aim to combine the developed degradation model and the available prognostic data together to provide an accurate and precise estimate of the system RUL.
4. *Elaboration of predictive maintenance policies.* Maintenance policies are developed based on the system RUL estimated from the last step. A learning phase will be help to determine suitable components to be repair or replacement at each intervention time.

The above developments can rely on a Mass-Spring-Damper deteriorating system recently studied by the supervisors [4, 5, 6, 7, 8].

Some related works:

[1] Huynh, K. T., Grall, A., & Bérenguer, C. (2018). A parametric predictive maintenance decision-making framework considering improved system health prognosis precision. *IEEE Transactions on Reliability*, 68(1), 375-396.

[2] Nguyen, K. T., Fouladirad, M., & Grall, A. (2018). Model selection for degradation modeling and prognosis with health monitoring data. *Reliability Engineering & System Safety*, 169, 105-116.

[3] Carvalho, T. P., Soares, F. A., Vita, R., Francisco, R. D. P., Basto, J. P., & Alcalá, S. G. (2019). A systematic literature review of machine learning methods applied to predictive maintenance. *Computers & Industrial Engineering*, 137, 106024.

[4] Huynh, K. T., Langeron, Y., & Grall, A. (2017). Degradation modeling and RUL estimation of deteriorating systems in S-plane. *IFAC-PapersOnLine*, 50(1), 12249-12254.

[5] La, T.M.H., Huynh, K.T., Langeron, Y., and Grall, A. Dégradation d'un système dynamique : modélisation dans le plan complexe. *In 21ème Congrès de Maîtrise des Risques et de Sûreté de Fonctionnement (λμ21)*, Reims, France, October (2018).

[6] La, T.M.H., Huynh, K.T., Langeron, Y., and Grall, A. Degradation modeling and condition-based maintenance decision-making for dynamic system in s-plane. *In 29th Annual European Safety and Reliability Conference (ESREL 2019)*, Hannover, Germany, September (2019), 538-545.

[7] Langeron, Y., Huynh, K.T., and Grall, A. Degradation and maintenance modeling of dynamic systems. *30th European Safety and Reliability Conference (ESREL2020) and 15th Probabilistic Safety Assessment and Management Conference (PSAM15)*. Accepted 19 November 2019.

[8] Langeron, Y., Huynh, K.T., and Grall, A. A root location-based framework for degradation modeling of dynamic systems with predictive maintenance perspective. *Proceedings of the Institution of Mechanical Engineers, Part O: Journal of Risk and Reliability*. Submitted 19 September 2019, Revised 11 February 2020, 2nd revision in process.

Research team:

The supervisors are with the Systems Modelling and Dependability Laboratory (webpage: https://recherche.utt.fr/system-modelling-dependability-m2s), Troyes University of Technology, France. The laboratory is organized into two main research projects: (*i*) decision and diagnostic in non-stationary environment, and (*ii*) stochastic models for reliability and maintenance. The applicant will be involved in the second one.

Collaborations:

1. Full Prof. Christophe Bérenguer, GIPSA-lab, Grenoble INP,
2. Full Prof. Anne Barros, Laboratoire Génie Industriel, Centrale Supélec.

Candidate profile:

The project realization requires knowledge in the fields of maintenance, machine learning, and control. We are looking for a candidate who holds an MSc degree and is familiar with one or more of the following themes:

1. Statistical inference, clustering,
2. Stochastic modeling and simulation,

3. Applied mathematics (probability, statistics).

A good level of programing (Matlab, R, Scilab, …) and of the English and/or French language is appreciated.

If the quality of the work is correct, the Ph.D. student will attend international conferences during the thesis.

Contact information:

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Google Scholar: https://scholar.google.fr/citations?user=ezkwuhUAAAAJ&hl