Sequential estimation for Ageing, Estimation and Sustainability

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1 Subject

Motivation

In many industrial problems it is an important issue to deal with deteriorating systems such as pipelines, wind turbine blades, a vehicle shock absorber, etc. The failure of such a system can have costly and disastrous consequences not only on humans but also on the environment. Hence, the failure of such a system should be predicted and its lifetime extended by mean of maintenance operations.

To predict a failure it is necessary to have knowledge about the future behavior of the system. This knowledge can be achieved by historical data on the deterioration or the failure times or the maintenance dates. Based on the available historical data a mathematical model can be proposed to predict the failure and its associated uncertainties.

Ageing modeling is the first step for failure prediction and maintenance of a system when data is available. A physical or mathematical model is associated to a health or aging indicator and based on this model the future behaviour can be estimated. A precise analyse of the ageing permits to avoid failure and the faulty behaviour of the system. The ageing systems undergo changes in their surrounding environment and by taking these factors in consideration we can improve the prediction precision.

The aging is influenced by several factors which cannot be all listed and their impacts cannot be necessarily modeled with a deterministic expression. That is why it could be seen as a random phenomenon and can be modelled by probabilistic tools. Stochastic models or processes are suitable tools to model this random evolution in time. The choice of an appropriate model for an ageing phenomenon is not an easy task and it depends on several aspects: the type of the components, the available information on the system (degradation or only failure), the point of view on the system (multi-component vision or one block vision), the dependency between the components of a system, the type of maintenance performed (corrective, preventive, planned, condition-based...), the type of equipment considered (specific individual or fleet of homogeneous materials), the nature of available data (covariates, incomplete data, abundant or rare).

To propose a useful and comprehensive approach of aging management, it is necessary to have a

flexible and tractable model useful for a large range of aging phenomenons. Semi-Markov models are appropriate candidates able to model a large variety of aging systems. These models can represent multi-state systems with time depend transition probabilities, more precisely, transition intensities taking into account the sojourn time in each state. Indeed, generally, the longer systems stay in critical deterioration states, the more severe their evolution is. Semi-Markov models play an important role in describing the evolution of an aging system. These models have been used in reliability problems ([10, 4]) and have delivered interesting results.

Moreover, nowadays, partly due to the massive automation of all processes (abundance of sensors), the development of modern communication means and a high demand on high frequency information, the society should deal with large scale data in a level never reached before. This high demand on instantaneous and reliable information has encouraged to find alternative data treatment methods. These methods permit a better condition-monitoring of complex systems (where the system health indicator is monitored during its lifetime) and lead to more reliable and sustainable systems. Monitoring data on the system or on its environmental conditions are used for maintenance planning in order to avoid failure or productivity losses.

In this framework, sequential estimation methods which propose an on-line estimation procedure during the condition-monitoring are perfect candidates to deal with on-line available information on the system under consideration.

Previous work and general layout of the thesis

We consider a deterioration phenomenon modeled by a semi-Markov process. The system is monitored continuously or by inspections. The available data could give the state of a health or performance indicator of the system. These two quantities are related and by modeling one the other can be deduced. The problem statement depends strongly on the given data and the way we handle the data. Based on the available information collected through monitoring, the transition probabilities and therefore the remaining useful lifetime are sequentially estimated. After each estimation, a maintenance action can be planned to avoid the failure and to reduce the risk occurrence of critical events. The study of the failure probabilities estimation permits to propose confidence intervals for the prediction results.

The aim of this thesis is to propose efficient sequential estimation methods for change and failure

detection of deteriorating systems modeled by a semi-Markov process and it can be seen as an extension of leads initiated by [3, 2, 16].

The different steps of this thesis can be resumed as follows:

1. Markov and sequential statistics
2. Renewal processes and sequential statistics
3. Semi-Markov and sequential statistics.
4. The sequential estimation of functionals of generator and semi-Markov kernels.
5. A sequential maintenance policy based on the estimation results is proposed.
6. A sensitivity analysis of maintenance performances to the estimations is carried out

The key knowledge and required skills to implement the previous steps are as follows:

1. Probability calculations for stochastic processes
2. Statistical inference, estimation and sensitivity analysis
3. Simulation and programming software: Matlab, or R, or Scilab, or PYTHON,...

Main collaboration on the subject

The candidate will organise and/or participate to meetings or seminars with the major industrial partners of the UTT on this subject.

2 Research team

This thesis is supervised by Nikolaos Limnios of the Compiègne Applied Mathematics Laboratory and Mitra Fouladirad of the Systems Modelling and Dependability Laboratory. They worked

during the last ten years on reliability problems and maintenance modelling for ageing systems and are qualified persons for the subject. They already supervised several thesis and their current works motivate the present proposal.

Nikolaos Limnios research interests focus on semi-Markov models, Statistical Inference for Stochastic processes and Reliability, [10, 15, 8, 16, 3, 4]. He is editorial board of several very well known journals: Communications in Statistics: Theory and Methods Communications in Statistics: Simulation and Computation, Methodology and Computing in Applied Probability, J. Statistical Theory and Practice, etc. Contacts: **Nikolaos.Limnios@utc.fr**.

Mitra Fouladirad research interests focus on maintenance modelling and joint maintenance/monitoring policies by using stochastic models to optimise maintenance and/or inspections policies (see references [7, 5, 6, 13, 14, 12, 11]). Contacts: **mitra.fouladirad@utt.fr**

Laboratory

The Compiègne Applied Mathematics Laboratory (webpage: http://www.lmac.utc.fr/) is a part of Mathematic Research Federation ARC of CNRS and it participates in research themes focused on applied mathematics and numerical calculation tools developments. The Compiègne Applied Mathematics Laboratory is organised into two main research projects: inverse problems and stochastic systems. The applicant will be involved in the last team.

The Systems Modelling and Dependability Laboratory (webpage: http://lm2s.utt.fr/en/index.html) is part of the LIST3N Department. The Systems Modelling and Dependability is organised into two main research projects: decision and diagnostic in non-stationary environment and stochastic models for reliability and maintenance. The applicant will be involved in the last team.

National collaborations

University of Rouen, University of Grenoble Alpes.

International collaborations

The candidate will be able to work with the usual international partners of the supervisors on the subject that is the research teams of:

- B. Lindqvist from Norwegian University of Science and Technology, Trondheim, Norway, (http://www.math.ntnu.no/ bo/)
- R Pérez-Ocón University of Granada Spain

If necessary, a research stay in one of these universities can be organised. What is more, if the quality of the work is correct, any Ph.D student of the team attends international conferences during the thesis.

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