Computers in Industry 141 (2022) 103716

Contents lists available at ScienceDirect

Computers in Industry

journal homepage: www.elsevier.com/locate/compind

An unsupervised approach for health index building and for similarity-based remaining useful life estimation

Sébastien Schwartz[a,*], Juan José Montero Jiménez[a,c], Rob Vingerhoeds[a], Michel Salaün[a,b]

[a] ISAE-SUPAERO, 10 Avenue Edouard Belin, Toulouse 31400, France
[b] Institut Clément Ader, 3 Rue Caroline Aigle, Toulouse 31400, France
[c] Tecnológico de Costa Rica, Calle 15, Avenida 14, Cartago 30101, Costa Rica

ARTICLE INFO

Article history:
Received 5 January 2022
Received in revised form 16 May 2022
Accepted 16 May 2022
Available online 4 June 2022

Keywords:
Kernel principal component analysis
Predictive maintenance
Prognostic
Similarity-based
Remaining useful life

ABSTRACT

Predictive maintenance techniques attempt to trigger a maintenance intervention at the right moment by estimating the life expectation. Predictive maintenance is increasingly implemented by automated approaches able to perform diagnostics and prognostics. The main part of recent research in these approaches is focused in machine learning structures whose reasoning is implicit and cannot be easily explained. This poses a problem for their implementation in highly constrained area such as aeronautics. To overcome this constraint, explicit reasoning approaches such as the Similarity-Based Model (SBM) can be implemented. The SBM has been widely used for fault diagnostics and the remaining useful life (RUL) estimation, but the development of SBM includes tasks that often rely on high skilled experts. For instance, data reduction techniques required for SBM are often performed by experts judgment whose outcomes are not always consistent. The produced features from these techniques are used to build the Health Index that can be used to create the degradation trends that serve as a reference for the SBM. To overcome these difficulties, an automatic and unsupervised approach based on the Kernel Principal Component Analysis is proposed to enhance the Health Index creation. It preserves as much of the sensor information as possible improving the similarity-based RUL estimation. Additionally, when estimating the RUL of a system, the most similar degradation trends stored in the SBM library are used to compute individual RULs, the final RUL is obtained by a fusion rule technique that combines all these individual RULs into a consolidated value. For the fusion rule techniques, a self-adaptive method that does not rely on human expertize is proposed. This fusion rule can benefit of the accumulated knowledge over the SBM operation. This unsupervised approach to develop a SBM is validated with promising results against an equivalent and supervised algorithm that came out best in the 2008 prognostic health management challenge.

1. Introduction

Predictive maintenance refers to a specific maintenance strategy, aiming at identifying incipient faults, forecasting future failures and at triggering the maintenance actions accurately when needed (Montero Jimenez et al., 2020). Maintenance strategies are often classified into three categories: (1) corrective maintenance where actions are performed to restore a system after a breakdown or a deteriorated functional behavior, (2) preventive maintenance where maintenance actions are performed at a fixed operational interval, and (3) predictive maintenance where specific maintenance actions are based on measurements on the concerned system. Remaining Useful Life (RUL) estimation plays an important role in predictive maintenance; it provides insight on the system deterioration due to faults appearance or wear, and tries to show when the system would no longer perform its intended function. As such, accurate RUL estimation improves safety, reliability and availability of the system. It attempts to avoid sudden breakdowns minimizing unnecessary maintenance time / cost (Gu and Chen, 2016). Therefore, it is important to focus on techniques that can improve RUL predictions, especially on high-risk engineering systems (Li et al., 2018; Yu et al., 2019; Zhao et al., 2017).

According to Ramasso and Saxena (2014), prognostics for maintenance can be divided into three broad categories as: functional mappings between set of inputs and RUL, such as Li et al. (2019), Jiang et al. (2019), functional mapping between Health Index (HI) and RUL, such as Hassani et al. (2019), Climente-Alarcon et al. (2017), and similarity-based matching, such as Bleakie and Djurdjanovic (2013), Liang et al. (2019), Zhang et al. (2019). The main focus of this work is on the use in aeronautics, where it is important that the

* Corresponding author.
E-mail address: sebastien.Schwartz@isae-supaero.fr (S. Schwartz).

https://doi.org/10.1016/j.compind.2022.103716