ARTICLE IN PRESS

Mechanical Systems and Signal Processing ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

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

Accurate bearing remaining useful life prediction based on Weibull distribution and artificial neural network

Jaouher Ben Ali [a,b,*], Brigitte Chebel-Morello [b], Lotfi Saidi [a], Simon Malinowski [b], Farhat Fnaiech [a]

[a] University of Tunis, National Higher School of Engineers of Tunis, Laboratory of Signal Image and Energy Mastery (SIME), 5 Avenue Taha Hussein. P.O. Box 56, 1008 Tunis, Tunisia
[b] FEMTO-ST Institute, AS2M Department, UMR CNRS 6174-UFC/ENSMM/UTBM, 25000 Besançon, France

ARTICLE INFO

Article history:
Received 10 January 2014
Received in revised form
1 October 2014
Accepted 29 October 2014

Keywords:
Prognostics and Health Management (PHM)
Remaining useful life (RUL)
Rolling element bearings (REBs)
SFAM
Weibull distribution (WD)

ABSTRACT

Accurate remaining useful life (RUL) prediction of critical assets is an important challenge in condition based maintenance to improve reliability and decrease machine's breakdown and maintenance's cost. Bearing is one of the most important components in industries which need to be monitored and the user should predict its RUL. The challenge of this study is to propose an original feature able to evaluate the health state of bearings and to estimate their RUL by Prognostics and Health Management (PHM) techniques.

In this paper, the proposed method is based on the data-driven prognostic approach. The combination of Simplified Fuzzy Adaptive Resonance Theory Map (SFAM) neural network and Weibull distribution (WD) is explored. WD is used just in the training phase to fit measurement and to avoid areas of fluctuation in the time domain. SFAM training process is based on fitted measurements at present and previous inspection time points as input. However, the SFAM testing process is based on real measurements at present and previous inspections. Thanks to the fuzzy learning process, SFAM has an important ability and a good performance to learn nonlinear time series. As output, seven classes are defined; healthy bearing and six states for bearing degradation. In order to find the optimal RUL prediction, a smoothing phase is proposed in this paper. Experimental results show that the proposed method can reliably predict the RUL of rolling element bearings (REBs) based on vibration signals. The proposed prediction approach can be applied to prognostic other various mechanical assets.

1. Introduction

Currently, traditional concepts of preventive and corrective maintenance are gradually submitted at new constraints of advanced required maintenance tasks. Many new advanced methods are very welcomed by the users in order to prevent degradation of their equipment. Hence, whatever the used method, it is important to anticipate the occurrence of defects in order to use protective actions. The main objective of this maintenance type is to ensure the dependability of industrial

* Corresponding author at: University of Tunis, National Higher School of Engineers of Tunis, Laboratory of Signal Image and Energy Mastery (SIME), 5 Avenue Taha Hussein. P.O. Box 56, 1008 Tunis, Tunisia. Tel.:+216 96568115/+216 52276629; fax: +21672486044.
E-mail address: benalijaouher@yahoo.fr (J. Ben Ali).

http://dx.doi.org/10.1016/j.ymssp.2014.10.014
0888-3270/

Please cite this article as: J. Ben Ali, et al., Accurate bearing remaining useful life prediction based on Weibull distribution and artificial neural network, Mech. Syst. Signal Process. (2014), http://dx.doi.org/10.1016/j.ymssp.2014.10.014

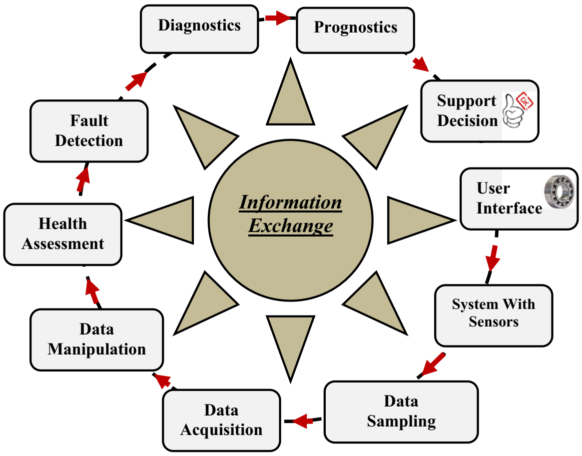

Fig. 1. PHM general scheme.

systems and to increase their availability with lower cost. The estimation of the remaining time of an equipment before failure helps the specialist in industries to avoid unnecessary spending time and money in maintenance. So, prognostics have become an important industrial issue and an appealing area of research to many researches. Prognostics are defined by the ISO 13381-1 as the estimation time to failure and risk of one or more existing assets and the prediction of future failure modes [1]. It is a promising activity that improves safety, availability of equipment and maintenance cost reduction. Prognostics and Health Management (PHM) is a process of detecting abnormal conditions, diagnosis of the fault and their cause and prognostics of the future fault progression [2].

In the literature, maintenance strategies are classified into three types [3]:

- Breakdown maintenance;
- Preventive maintenance;
- Condition-Based Maintenance (CBM).

Breakdown maintenance and preventive maintenance are disappearing from industrial practice as they are based on the repair of an asset when it breaks down, and periodic inspection and replacement. The main advantage of CBM is to control continuously a process to choose the best intervention time and to not interrupt normal operations. Thereby, CBM is widely targeted in research and industry nowadays. PHM, as shown in Fig. 1, is the most important activity of CBM. PHM is developed from fault detection to diagnostics and throughout prognostics. The main prognostic objective is to estimate the remaining time before total failure of assets [4]. So, reducing maintenance costs of critical industrial assets is one of the most important advantages of prognostics.

In the literature, there are three different approaches to prognostics [5]:

- The physical model developed by experts and validated on large sets;
- The rule based expert systems;
- The data-driven model.

In this work, we develop a novel data-driven prognostic approach based on vibration signals suitable for rotating mechanical assets. Our challenge is to define on a first hand a new feature which characterizes more accurately bearing degradations and on a second hand to simplify the prognostic task into a classification task. For this, we propose a new approach based on Weibull distribution and artificial neural network which is validated by an application on bearings. A modified Weibull Failure Rate Function (WFRF) called Universal Failure Rate Function (UFRF) is used to fit extracted features in the time domain based on vibration signals. Then, fitted features are used to train Simplified Fuzzy ARTMAP (SFAM) neural network. SFAM training mode is done with seven classes: healthy bearing and six states for bearing degradation. An intelligent smoothing phase is introduced to perform accurate RUL prediction. Experimental results based on bearing run-to-failure vibration signals demonstrate that the proposed method is able to track the regularity of bearing degradations sensitively and accurately.

The remainder of this paper is organized as follows: a detailed literature review is presented in Section 2 related to prognostics for bearing applications. Section 3 presents the different steps of the proposed method. In this section, the feature extraction process is given and the basic principles of Weibull distribution and SFAM neural network are detailed. Section 4 describes the simulation and experimental results as well as some numerical examples to assess the effectiveness of the proposed method. Section 5 is dedicated to discuss and analyse the experimental results by comparing the obtained performances with respect to other approaches. Finally, some conclusions and future works are provided in Section 6.

Please cite this article as: J. Ben Ali, et al., Accurate bearing remaining useful life prediction based on Weibull distribution and artificial neural network, Mech. Syst. Signal Process. (2014), http://dx.doi.org/10.1016/j.ymssp.2014.10.014