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GAS TURBINE HEALTH CLASSIFICATION USING A HYBRIDIZED OPTIMIZATION ALGORITHM

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ABSTRACT

Modern gas turbine engines have been designed to have high levels of reliability and low incidences of failures. The high number of components, and the economic necessity to replace functional systems in a modular manner in the field to maintain operation, can make fault classification problematic if too few specific failures can be identified in historic datasets. Such cases present the problem of having to perform cluster analysis despite the true number of clusters being unknown a-priori—this constitutes a generic problem which is not unique to engine health monitoring. Whilst a variety of approaches to accommodate this deficiency have been presented in the literature, the majority seek a unique solution for the *k*-number of clusters. By contrast, this work applies a multi-objective approach that returns a Pareto optimal set of solutions. This approach is particularly suitable when the number of modes of operation (clusters) is unknown, and employs a new hybridized, multi-objective optimization algorithm that provides the solutions for *k-means* clustering. In the present work, the computational load of clustering gas turbine monitoring data using the proposed hybridized optimization algorithm is compared to the load imposed by using two alternative state-of-the-art multi-objective optimizers (differential evolution and particle swarm). It is shown that the new algorithm both accelerates convergence and, reduces the computational overhead for this classification task.

Keywords: classification, clustering, health monitoring, multi-objective, optimization.

INTRODUCTION

An application of health monitoring for gas turbine engines is presented for the diagnosis of abnormal behaviour using data from on-engine monitors. Several modes of healthy behaviour may exist, along with several other operational modes that indicate problems with the engine, or the gradual emergence of a fault condition. Being able to efficiently diagnose or predict faults can significantly reduce engine downtime, and thus cost, if preventative maintenance can be performed (Gallimore, 2011).

For the presented work, historic datasets from on-engine logging are used off-line to build a discriminator of common operating behaviours. Specifically, datasets from 13 different gas turbines of the same class (sub 15MW units) are employed. The full dataset contains 592 shaft rundown/shutdown instances (from ~12,000rpm) with a shaft vibration sensor being used as the dependant variable - see Fig 1(a) for a single rundown instance. It should be noted that the proposed method is not limited to *k-means* clustering and could readily be used with alternative clustering algorithms, as in (Duke, 2004). In this way, it is anticipated that when deployed operationally, the solution will be one that both discriminates clearly the 'out-of-sample' rundowns, and, be a solution where the *k*-clusters represent the true *k*-rundown modes. Distinguishing the current work is the new, proposed multi-objective optimization algorithm and its relatively low computational overhead (measured by the number of clustering calls). A bio-inspired global optimization algorithm (based on Lévy-flights) is hybridized with a direct search method for more rapidly polishing locally-optimal solutions. Finally, a human expert determines the ultimate choice from the Pareto optimal set of solutions-see Fig. 1(b) for instance.

RESULTS AND CONCLUSIONS

Candidate results are shown in Fig.1(b) which shows a Pareto optimal set found using the proposed multi-objective approach on the 592 sample training set. The Utopian point would lie in the bottom left hand corner. The data labels in Fig.1(b) display the associated values of *k* found by the proposed methodology. From this Pareto optimal set, a human expert - given their specialist gas turbine experience - can select the most appropriate *k*.

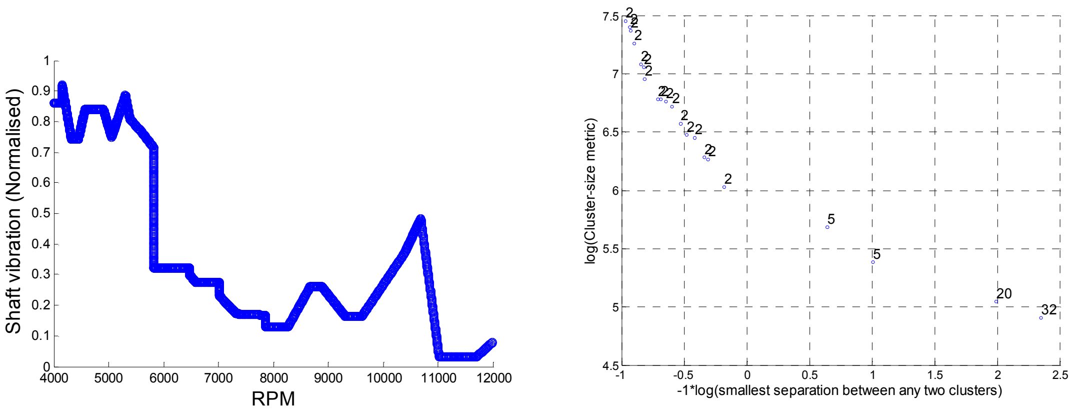

Fig. 1 - (a) Example turbine rundown signature (b) Pareto set of rundown modes for this turbine class

The technique presented in the paper refines the (previously unknown) *k*-number of rundown modes intrinsic to this gas turbine family. In the full version of our paper, the new optimization algorithm is benchmarked on this same problem, with two alternative, but likewise bio-inspired, optimization algorithms: Differential Evolution and Particle Swarm Optimization as implemented in MATLAB (Oldenhuis, 2010). It is thereby shown that the computational overhead has been significantly reduced using the new algorithm.

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