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Optimal filter design with progressive genetic algorithm for local damage detection in rolling bearings

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ABSTRACT

Harsh industrial conditions present in underground mining cause a lot of difficulties for local damage detection in heavy-duty machinery. For vibration signals one of the most intuitive approaches of obtaining signal with expected properties, such as clearly visible informative features, is prefiltration with appropriately prepared filter. Design of such filter is very broad field of research on its own. In this paper authors propose a novel approach to dedicated optimal filter design using progressive genetic algorithm. Presented method is fully data-driven and requires no prior knowledge of the signal. It has been tested against a set of real and simulated data. Effectiveness of operation has been proven for both healthy and damaged case. Termination criterion for evolution process was developed, and diagnostic decision making feature has been proposed for final result determinance.

1. Introduction

In the field of machine diagnostics based on vibration signal analysis, information about the damage is placed in so called informative frequency band (IFB) [1]. Span of this band depends on many factors, such as kinematic structure, operational conditions, type of damage and its location within the machine. In other words: it depends on design, operational, change of conditions factors as was stated by Bartelmus [2]. In most cases neither those factors nor information about IFB are known. Facing such limitations, it is clear that pursuit for automatic, data-driven methods is the most desirable direction of research. Many different techniques for IFB identification have been developed over the years, such as adaptive wavelet-based filtration [3,4], filtering with spectral kurtosis [5,6], modulation intensity distribution [7], empirical mode decomposition [8–10], selectors [11–13], protrugram [14], sparsogram [15,16] or stochastic resonance [17].

In presented solution authors pursue the approach of determining IFB, and hence extracting information about the presence of damage, that is based on optimal filtration. In opposition to using classic adaptive filters [18,19] or designing optimal filter prior to predefined specification [20], presented approach is fully data-driven, and fitness function evaluates the solutions only in terms of filtration performance. This way no functional constraints are imposed on the way that filter is constructed by the evolution process. Real-life data utilized in this paper were previously addressed in [21].

From mathematical point of view, filter is just an equation of discrete transfer function with N coefficients. For optimal filtering, both the value of N and coefficients values should be found. From such perspective, diagnostic methodology can be considered as multidimensional optimization problem. Genetic Algorithm (GA) is one of the most frequently used tool for

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that task. However, it should be noted that presented procedure is not a simple application of GA to filter design. Authors proposed a complete progressive procedure for data-driven arbitrary filter development having no prior requirements. Kurtosis of filtered signal is used as a fitness function, since local damage in rotating machines presents itself as wideband impulses in vibration signal. However, an original concept of termination procedure is proposed. In this paper, progressive genetic algorithm has been applied for the design of linear phase digital FIR filter. Presented method is compared with filtration based on spectral kurtosis (SK) and kurtogram, which are selected as the classical methods of custom filtration.

2. Methodology

2.1. Genetic algorithm

In computer science and operations research, a genetic algorithm (GA) is a metaheuristic inspired by the process of natural selection that belongs to the larger class of evolutionary algorithms (EA) [22]. Genetic algorithms are commonly used to generate high-quality solutions to optimization and search problems by relying on bio-inspired operators such as mutation, crossover and selection [23]. This idea appeared first in 1967 in J.D. Bagley's thesis "The Behavior of Adaptive Systems Which Employ Genetic and Correlative Algorithms" [24]. The theory and applicability was then strongly influenced by J.H. Holland, who can be considered as the pioneer of genetic algorithms [25,26]. Since then, this field has witnessed a tremendous development.

Basic structure of a genetic algorithm presents itself as follows (see Fig. 1).

As obvious from the above algorithm, the transition from one generation to the next consists of four basic components [23]:

- **Selection:** Mechanism for selecting individuals (strings) for reproduction according to their fitness (objective function value).
- **Crossover:** Method of merging the genetic information of two individuals; if the coding is chosen properly, two good parents produce good children.

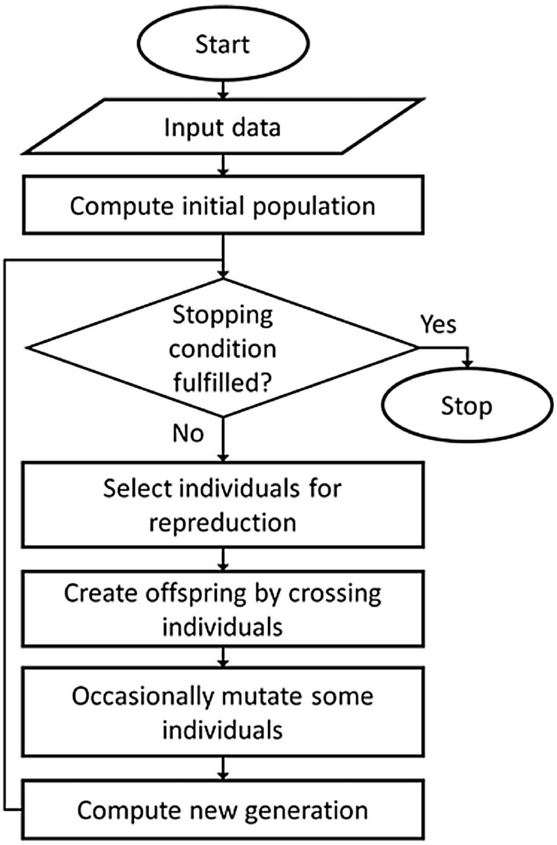

Fig. 1. Functional flowchart of genetic algorithm.