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Atomic Decomposition and Sparse Representation for Complex Signal Analysis in Machinery Fault Diagnosis: A Review with Examples

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Abstract: Complex signal analysis is a key topic in machinery fault diagnosis. For complex multi-component signals of various morphological contents, the commonly used basis expansion based signal processing method lacks adaptability and flexibility, thus being ineffective to extract the embedded meaningful information. Sparse signal representation has excellent adaptability and high flexibility in describing arbitrary complex signals based on atomic decomposition over redundant and over-complete dictionary, thus being free from the limitations imposed by orthogonal basis, and providing an effective approach to feature extraction from intricate signals for machinery fault diagnosis. This paper presents a systematic review on sparse signal representation, especially on two key topics, i.e. atomic decomposition algorithms (such as greedy pursuit, l_p norm regularization and iterative shrinkage/thresholding) and dictionary design methods (including analytic dictionary design and dictionary learning) reported in more than 70 representative articles published since 1990. Their fundamental principles, advantages and disadvantages, and applications to machinery fault diagnosis, are examined. Some examples are provided to illustrate their performance.

Keywords: fault diagnosis; sparse representation; atomic decomposition; dictionary.

1 Introduction

Many sorts of modern machinery are composed of mechanical, electrical and hydraulic systems. Their dynamic responses are a complex mixture of various dynamic phenomena, including mechanical vibrations, electrical oscillations, hydraulic fluctuations, their coupling effects, and the dynamic responses to environmental excitations. As a consequence, their dynamic responses feature high degree of complexity and various types of morphology.

Machinery differ from each other in terms of kinematics, thus their dynamic responses have respective distinct characteristics. For example, rotor or shaft vibrations are usually dominated by rotating frequency and its harmonics. Gear vibrations are mainly composed of rotating frequency and its harmonics, as well as amplitude modulation and frequency modulation (AM-FM) components, wherein the signal carrier frequency is the gear meshing frequency and its harmonics, the AM and FM