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Sparse and low-rank methods in structural system identification and monitoring

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Abstract

This paper presents sparse and low-rank methods for explicit modeling and harnessing the data structure to address the inverse problems in structural dynamics, identification, and data-driven health monitoring. In particular, it is shown that the structural dynamic features and damage information, intrinsic within the structural vibration response measurement data, possesses sparse and low-rank structure, which can be effectively modeled and processed by emerging mathematical tools such as sparse representation (SR), and low-rank matrix decomposition. It is also discussed that explicitly modeling and harnessing the sparse and low-rank data structure could benefit future work in developing data-driven approaches towards rapid, unsupervised, and effective system identification, damage detection, as well as massive SHM data sensing and management.

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Keywords: Type your keywords here, separated by semicolons ;

1. Introduction

Vibration-based response measurements (e.g., strains, displacements, and accelerations) and analysis techniques such as modal analysis based system identification and damage detection methods have been widely studied for SHM [1,2]. Traditional modal identification typically complies with the principle of system identification which is based on the relationship of inputs and outputs [1,2,3]. For civil structures, typically large-scale (e.g., bridges, buildings, dams, etc.), it is extremely difficult or expensive, if not impossible, to apply controlled excitation to conduct input-output modal analysis. Accurate measurement of the ambient excitation (e.g., wind, traffic, etc.) to structures is also

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challenging. Therefore, in practical applications, it is often required to identify the structural dynamic properties from only the available structural vibration response measurement data. This is essentially an ill-posed inverse problem, which hardly has analytical solutions. Solving the ill-posed inverse problem where only the structural vibration response measurements are available needs additional, prior, knowledge or assumption. If detailed knowledge of the structure is available, including material property, geometry, component connections and joints, boundary conditions, etc., a common approach to solving the inverse problem is to build a physics based or physical model of the structure, such as a finite element model, as the reference information of the initially healthy structure. Afterwards, the structural model is updated by fitting the model-predicted responses with the current structural responses (usually modal parameters) [1,2,3]. In the context of the need of performing output-only modal parameters identification from the current structural vibration response measurements, many established methods, such as Ibrahim time domain (ITD) method [1,2], eigensystem realization algorithm (ERA) [1,2], and stochastic subspace identification (SSI) [1,2], (note: frequency domain decomposition (FDD) [1,2] is non-parametric) include a process of building a parametric dynamic model such as state space model, and then estimating the dynamic parameters of the dynamic model by fitting the structural response measurements. Finally, one obtains the system or dynamic parameters (e.g., by eigen analysis) from the updated structural model, and the discrepancy between the updated and reference models (physical or modal models) indicates structural damage.

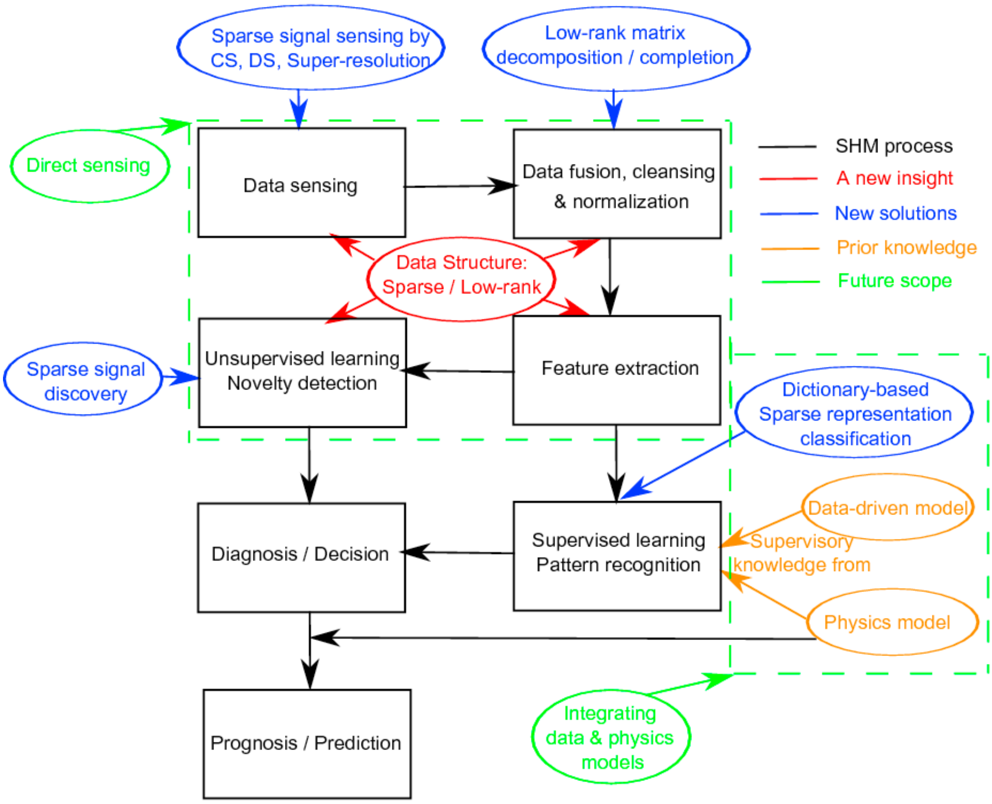

Fig. 1. The framework of the new paradigm of explicitly modeling the sparse and low-rank data structure (presented in this paper) for structural system identification and structural health monitoring.

An alternative approach is to directly exploit the available structural vibration response measurement data itself. Unlike parametric model based methods which are derived from the (mathematically) physical processes, data-driven approaches aim to extract the desirable information directly from the available data, without explicit knowledge of the physical or dynamic model of the underlying system. The non-parametric data-driven algorithms are efficient and have potential for real-time processing the massive SHM data.

This paper contributes to present an alternative paradigm of explicitly modeling and harnessing the inherent data