Chapter 13
Unsupervised Learning Techniques for Vibration-Based Structural Health Monitoring Systems Driven by Data:
A General Overview

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ABSTRACT

Structural damage detection is a crucial issue for the safety of civil buildings, which are subject to gradual deterioration over time and at risk from sudden seismic events. To prevent irreparable damage, the scientific community has directed its attention toward developing innovative methods for structural health monitoring (SHM), which can provide a timely and reliable assessment of structural conditions. In this domain, the significance of unsupervised learning approaches has grown considerably, as they enable the identification of structural irregularities solely based on data obtained from intact structures to train statistical models. Despite the importance of studies on unsupervised learning methods for structural health monitoring, no reviews are specifically dedicated to this topic, considering the application part. The review of studies, therefore, made it possible to highlight the progress achieved in this field and identify areas where improvements could still be made to develop increasingly accurate and effective methods for structural damage detection.

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INTRODUCTION

Civil engineers consistently face the challenge of ensuring the stability of civil buildings, given that these constructions endure many degradation factors, such as extended usage, adverse environmental conditions, and the potential for seismic events. To safeguard against the potential loss of life and property resulting from sudden or gradual damage, they have devised approaches and regulations for structural assessment and evaluation(Lorusso & Celenta, 2023a). These methods encompass visual inspection and non-destructive damage estimation techniques. Nevertheless, these conventional approaches may come with high expenses, time demands, and potential hazards for operators(Dhruva Kumar et al., 2023). For this reason, the scientific community is focusing on the development of SHM, which can provide a real-time assessment of the state of structures, thanks to continuous advances in the hardware part of the systems, such as the ongoing development of the IoT paradigm through real-time monitoring(Deivasigamani et al., 2013; Kumar & Kota, 2023). Undoubtedly, the field of civil engineering has greatly profited from the advancement of sensor technology and machine learning (ML)(Padmapoorani et al., 2023). SHM research has also reaped the rewards of these progressions, as an ever-growing array of SHM approaches now incorporates deep learning (DL) frameworks(Bezas et al., 2020). Specifically, extensive research efforts have been directed toward monitoring the health of facilities using unsupervised learning algorithms. These methodologies rely on analyzing data obtained from intact structures to develop statistical models, eliminating the need for supplementary information regarding the structures' condition(Meribout et al., 2021). Within this context, novelty detection using vibration data is the widely acknowledged approach for unsupervised learning in SHM (Arcadius Tokognon et al., 2017). Recent scientific literature has extensively explored ML-based SHM techniques, encompassing applications of DL (DL) and reinforcement learning, with a special emphasis on vibration analysis. Moreover, researchers have also investigated the effectiveness of CNNs in SHM methods(De Simone et al., 2022). However, to date, there are no systematic literature reviews on unsupervised learning SHM methods taking into account possible applications, which is one of the most promising research areas for the implementation of an effective and practical structural damage detection system to support predictive monitoring(Lorusso & Guida, 2022). Some of the models studied introduced a statistical pattern recognition approach divided into phases, i.e., operational assessment, data acquisition, feature selection, and the increase of statistical models for diversifying these features. Despite the primary focus of the analyzed studies being on the last two stages, several approaches emphasise feature selection rather than pattern development (Sarah et al., 2019)t. Certainly, the main objective of statistical models is to identify possible harm by ascertaining its presence, position, and scope. In recent times, there have been noteworthy advancements in the field of SHM, with particular emphasis on vibration-based and visual-based methods (Fig.1) (Lorusso & Celenta, 2023b)(Martens et al., 2023). The visual-based approach leverages state-of-the-art computer vision techniques and unmanned aerial vehicles (drones) to conduct visual inspections autonomously. These innovative developments have contributed to the progress and effectiveness of SHM methodologies. On the other hand, vibration-based SHM relies on gathering vibration data from structures to identify structural damage that may prove challenging to detect through conventional inspection methods. In the field of SHM, there are two main categories of vibration-based monitoring: model-based and data-based(G. Hou et al., 2022). Model-based techniques require specific skills to develop accurate physical models of structures, calibrated using data collected from the structure itself. System recognition and model refinement techniques are fundamental to the functioning of model-based techniques. However, such procedures can be time-consuming and costly, especially for