Chapter 1
Strain Field Pattern Recognition for Structural Health Monitoring Applications

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ABSTRACT

Strain field pattern recognition, also known as strain mapping, is a structural health monitoring approach based on strain measurements gathered through a network of sensors (i.e., strain gauges and fiber optic sensors such as FGBs or distributed sensing), data-driven modeling for feature extraction (i.e., PCA, nonlinear PCA, ANNs, etc.), and damage indices and thresholds for decision making (i.e., Q index, T2 scores, and so on). The aim is to study the correlations among strain readouts by means of machine learning techniques rooted in the artificial intelligence field in order to infer some change in the global behavior associated with a damage occurrence. Several case studies of real-world engineering structures both made of metallic and composite materials are presented including a wind turbine blade, a lattice spacecraft structure, a UAV wing section, a UAV aircraft under real flight operation, a concrete structure, and a soil profile prototype.

INTRODUCTION

Structural health monitoring (SHM), as a discipline named in this way, started about four decades ago (Boller, 2008). Since then, several definitions have been proposed being the one by Boller (2008), the most accepted one. According to this definition, SHM consists in the integration of sensing and/or actuating devices in order to record, analyze, localize and predict the damage and infer the load conditions of a structure in such a way that nondestructive testing (NDT) becomes an integral part of the structure (Boller, 2008).

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Several classification schemes have also been stated, however, the most complete includes seven basic levels serving as the objectives to achieve by an SHM system (Farrar & Worden, 2007). In the following proposed classification, load monitoring has been included in order to match with the broad definition of SHM proposed by Boller (2008).

Level 1: Monitor and record the loads.
Level 2: Determine the existence of the damage.
Level 3: Determine the location of the damage.
Level 4: Determine the kind of damage.
Level 5: Quantify the severity of the damage.
Level 6: Estimate the remaining lifetime.
Level 7: Develop capacities for self-diagnosis and self-healing.

Up to date, the scientific community has provided laboratory solutions under simulated operational conditions mainly for the first five levels of this damage assessment scheme. Among the reasons for a slow development of real-world SHM applications is the uncertainty involving damage assessment. The major progression in this aspect has been accomplished in the context of condition monitoring in rotating machinery due to the large amount of available data and the predictable nature of the damages typically presented in this type of structures (Lopez & Sarigul-Klijn, 2010). This chapter is mainly focused on the first two levels of the scheme, namely, load monitoring and damage detection, where most of the studies have been focused on.

The importance of damage detection in structures is related to the fact that materials deteriorate with time and usage due to several types of loads. It is paramount to guarantee in all engineering structures their serviceability and reliability during their lifetime. In addition, damage-tolerant designs, specifically used in the aerospace field, require the proper identification of damages since they can grow until a state where the integrity of the structure is not at risk. This led to lighter structures and more efficient designs (Rocha et al., 2013).

Historically, early studies within the context of damage detection focused on physical models such as stiffness and modal parameter determination. Such approaches rely on deterministic modeling where all variables are assumed to be measurable and several uncertainties are not directly included in the model. Consequently, it is complex to determine the reliability of such estimation. This is even more difficult when considering the tendency in several industries to use sophisticated designs and materials in order to increase efficiency and performance. Thus, the physical modeling of the actions and responses in the state-of-the-art engineering structures is difficult to accomplish.

Here, is where statistical pattern recognition comes to play, since it is possible to use approaches that develop data-driven models through machine learning algorithms instead of using complex physical models. Data-driven models rely on experimental data for *training* or *learning* the current state of a structure. These approaches have proved to be robust in the damage assessment tasks. However, some difficulties are posed such as variability related to the physical system and the environment where it operates and the management of a large amount of data (Figueiredo & Santos, 2018).

In the damage detection process in an online and automated way using statistical pattern recognition, it is common that every SHM system addresses four stages: operational evaluation, data acquisition, feature extraction and statistical modeling for decision-making. Operational evaluation aims to customize the damage detection process by considering the limitations based on the characteristics of the structure

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