Data Mining for Structural Health Monitoring

Ramdev Kanapady
University of Minnesota, USA

Aleksandar Lazarevic
United Technologies Research Center, USA

INTRODUCTION

Structural health monitoring denotes the ability to collect data about critical engineering structural elements using various sensors and to detect and interpret adverse "changes" in a structure in order to reduce life-cycle costs and improve reliability. The process of implementing and maintaining a structural health monitoring system consists of operational evaluation, data processing, damage detection and life prediction of structures. This process involves the observation of a structure over a period of time using continuous or periodic monitoring of spaced measurements, the extraction of features from these measurements, and the analysis of these features to determine the current state of health of the system. Such health monitoring systems are common for bridge structures and many examples are citied in (Maalej et al., 2002).

The phenomenon of damage in structures includes localized softening or cracks in a certain neighborhood of a structural component due to high operational loads, or the presence of flaws due to manufacturing defects. Damage detection component of health monitoring system are useful for non-destructive evaluations that are typically employed in agile manufacturing systems for quality control and structures, such as turbine blades, suspension bridges, skyscrapers, aircraft structures, and various structures deployed in space for which structural integrity is of paramount concern (Figure 1). With the increasing demand for safety and reliability of aerospace, mechanical and civilian structures damage detection techniques become critical to reliable prediction of damage in these structural systems.

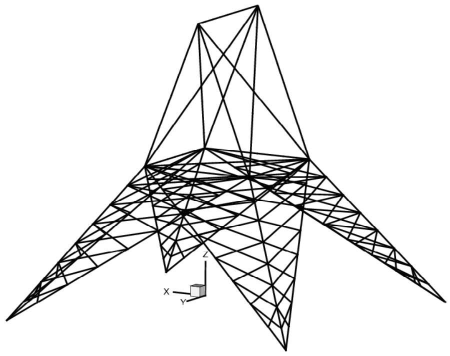
Most currently used damage detection methods are manual such as tap test, visual or specially localized measurement techniques (Doherty, 1997). These techniques require that the location of the damage have to be on the surface of the structure. In addition, location of the damage has to be known a priori and these locations have to be readily accessible. This makes current maintenance procedure of large structural systems very time consuming and expensive due to its heavy reliance on human labor.

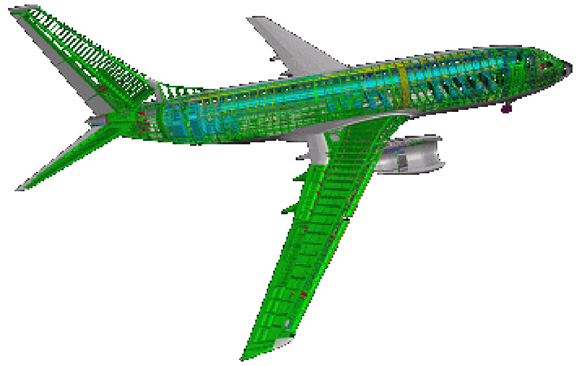
BACKGROUND

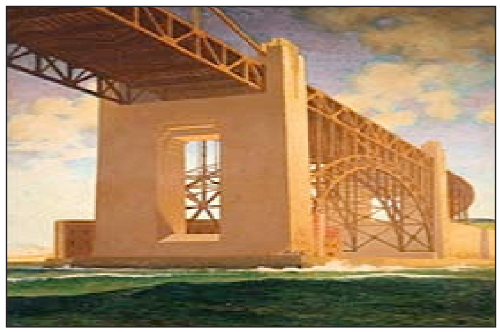
The damage in structures and structural systems is defined through comparison between two different states of the system, where the first one is the initial undamaged state, and the second one is damaged state. Emerging continuous monitoring of an instrumented structural system often results in the accumulation of a large amount of data that need to be processed, analyzed and interpreted for damage detection. However, the rate of accumulating such data sets far outstrips the ability to analyze them manually. As a result, there is a need to develop an intelligent data processing component that can significantly improve current damage detection systems. Since damage in changes in the properties of the structure or quantities derived from these properties, the process of health monitoring eventually reduces to a form of data mining problem. Design of data mining techniques that can enable efficient, real-time and robust (without false alarm) prediction of damage presents one of key challenging technological opportunity.

In recent years, various data mining techniques such as artificial neural networks (ANNs) (Anderson et al., 2003; Lazarevic et al., 2004; Ni et al., 2002; Sandhu et al., 2001; Yun & Bahng, 2000; Zhao, Ivan & DeWolf, 1998;), support vector machines (SVMs) (Mita & Hagiwara 2003), decision trees (Sandhu et al., 2001) have been successfully applied to structural damage detection problems. This success can be attributed to numerous disciplines integrated with data mining such as pattern recognition, machine learning and statistics. In addition, it is well known that data mining techniques can effectively handle noisy, partially incomplete and

Figure 1. Examples of engineering structures that require structural health monitoring systems







faulty data, which is particularly useful, since in damage detection applications, measured data are expected to be incomplete, noisy and corrupted.

The intent of this chapter is to provide a survey of emerging data mining techniques for structural health monitoring with particular emphasis on damage detection. Although the field of damage detection is very broad and consists of vast literature that is not based on data mining techniques, this survey will be predominantly focused on data-mining techniques for damage detection based on changes in properties of the structure.

CATEGORIZATION OF STRUCTURAL DAMAGE

The damage in structures can be classified as linear or nonlinear. Damage is considered as linear if the undamaged structure remains elastic after damage. However, if the initial structure behaves in a nonlinear manner after the damage initiation, then the damage is considered as nonlinear. However, it is possible that the damage is linear at the damage initiation phase, but after prolonged growth in time, it may become nonlinear. For example, loose connections between the structures at the joints or the joints that rattle (Sekhar, 2003) are considered non-linear damages. Examples of such non-linear damage detection systems are described in (Adams & Farrar, 2002; Kerschen & Golinval, 2004).

The most of the damage detection techniques in the literature are proposed for linear case. They are based on the following three levels of damage identification: 1. Recognition—qualitative indication that damage might be present in the structure, 2. Localization—information about the probable location of the damage in the structure, 3. Assessment—estimate of the extent of severity of the damage in the structure. Such damage detection techniques can be found in several approaches (Yun & Bahng, 2000; Ni et al., 2002; Lazarevic et al., 2004).

CLASSIFICATION OF DAMAGE DETECTION TECHNIQUES

We provide several different criteria for classification of damage detection techniques based on data mining.

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