

# Chapter 33

## New Features for Damage Detection and Their Temperature Stability

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### ABSTRACT

*This chapter is devoted to present novel techniques in Structural Health Monitoring (SHM). These techniques are based on different statistical and signal processing methods that are used in other fields but their performance and capability in SHM is presented and tested for the first time in this work. This work is dedicated to the first level of SHM, which might be considered the main and most important level. Piezoceramic (PZT) devices are chosen in this work to capture the signals due to their special characteristics such as high performance, low energy consumption and reasonable price. Suggested techniques are tested on different laboratory and real scale test benchmarks. Moreover, this work considers the effect of environmental changes on performance of the presented techniques. This work shows that although those techniques have a significant result in normal conditions, their performance can be affected by any environmental discrepancy such as temperature change. As such, there is a vital need to consider their effect. In this work, temperature change is chosen, as it is one of the main environmental fluctuation factors.*

### WAVE CLUSTERING

The aim of data-clustering methods is to group the objects in databases into meaningful subclasses. Clustering tries to detect groups and assign labels to the objects based on the cluster that they belong to. A good clustering algorithm should be time efficient, order-insensitive and be able to identify clusters irrespective of their shapes and relative position. Clustering algorithms are categorized into four

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main groups: partitioning algorithms (Kaufman & Rousseeuw 2005), hierarchical algorithms (Zhang, Ramakrishnan, & Livny 1996), density based algorithms (Ester et al. 1996) and grid based algorithms (Sheikholeslami, Chatterjee, & Zhang 1998; Xu & Ester 1998).

Partitioning methods relocate instances by moving them from one cluster to another, starting from an initial partitioning. To do this, some iterative control strategy is used to optimize an objective function such as Error Minimization Algorithm ( $k$  – means) (Kaufman & Rousseeuw 2005), Graph-Theoretic Clustering (Urquhart 1982), and others.

Hierarchical algorithms construct the clusters by recursively partitioning the instances. This algorithm iteratively splits the database into smaller subsets until some termination condition is satisfied. Comparing with partitioning algorithm, hierarchical algorithms do not need  $k$  as input parameter. This is an advantage but in contrary the termination condition need to be declared (Rokach & Maimon 2010).

Density based algorithm allocate the observation with the similar probability distribution to the same cluster. The overall distribution of the data is assumed to be a mixture of several distributions. This algorithm aims to identify the cluster and its distribution parameter (Ester et al. 1996).

Grid based methods partition the space into a finite number of cells that form a grid structure on which all of the operations for clustering are performed. The main advantage of the approach is its fast processing time because it is independent of the number of objects. In this work we apply a spatial data-mining method termed Wave Cluster developed by (Sheikholeslami, Chatterjee, & Zhang 1998, 2000) that belongs to this category.

Wave Cluster is an efficient method with low computational complexity. The results are less affected by noise and the method is not sensitive to the order of input objects. According to (Sheikholeslami, Chatterjee, & Zhang 2000) the main idea of Wave Cluster is to transform the original feature space by applying wavelet transform and then find the dense regions in the new space. According to them, in this procedure the process of finding the connected components in the transformed space is easier than in the original feature space, because the dense regions in the feature space will be more salient. Applying wavelet transform on a signal decomposes it into different frequency sub-bands. The high frequency parts of the signal are related to the regions where there is a rapid change such as boundaries of cluster, while the low frequency part corresponds to the areas that the objects are more concentrated, the cluster themselves. In another words, observations in a  $2D$  feature space are considered as an image where each pixel of image corresponds to one cell in the feature space. To achieve this goal, the discrete wavelet transform (DWT) is used. Using DWT, details and approximation of signal are decomposed for different steps. Approximation or average sub-band carries information about content of cluster and details sub-bands have information about the boundaries of clusters.

The multidimensional spatial data objects can be represented in a  $d$  – dimensional *feature space*. For an object with  $d$  numerical attributes, the feature vector will be one point in  $d$  – dimensional feature space. Wave Cluster proposes to look at the feature space from signal processing perspective. It means that the high frequency parts of the signal correspond to the regions of the feature space where there is a rapid change in the distribution of objects, that is, the boundaries of clusters. The low-frequency parts of the  $d$  – dimensional signal that have high amplitude correspond to the areas of the feature space where the objects are concentrated, in other words, the clusters themselves. For instance, Figure 1 presents a  $2D$  feature space where each point of the image represents the feature values of one object in spatial dataset. Thanks to the properties of wavelet transform for detecting rapid changes in the signal, we can apply wavelet transform to find high-frequency and low-frequency parts of the  $d$  – dimensional signal that bring about clusters detection.

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