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Artificial Immune System (AIS) for Damage Detection Under Variable Temperature Conditions

Maribel ANAYA[1,2] , Diego TIBADUIZA[1], Francesc POZO [2]

[1] Faculty of Electronics Engineering, Universidad Santo Tomás,
Bogotá, COLOMBIA, maribelanaya@usantotomas.edu.co , diegotibaduiza@usantotomas.edu.co,
[2] Dpt Mathematics, Universitat Politecnica de Catalunya
Barcelona (SPAIN) francesc.pozo@upc.edu

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Abstract

Early damage detection remains one of the priorities of the structural health monitoring systems in the task of continuous monitoring. In this kind of systems different approaches can be used, however data-driven systems are requested because the information from the sensors is obtained directly from the structure in real operational and environmental conditions. Some of these approaches makes use of acousto-ultrasonics (AU) techniques, which offer the possibility of inspecting large areas of structures, by using a piezoelectric active sensor network. However, these kind of inspection systems are affected by the variations in the environmental conditions. In this sense, is a need to still working in more and better damage detection techniques. This paper describes a health monitoring methodology combining the advantages of guided ultrasonic waves together with artificial immune systems as a pattern recognition technique to determine the effects of the temperature in the damage detection process, in addition, a sensor data fusion with the data from different temperatures is proposed as a hefty baseline to consider the healthy structure under different temperature conditions and discarding the resultant false positives by the changes in temperature. Experimental results are included to demonstrate the temperature effects and how the methodology improves the damage detection capabilities.

1 INTRODUCTION

One of the most important task in the development of pattern recognition approaches is the capability of providing a reliable pattern. This is a need because the analysis to discern changes in the data is provided over the baseline pattern. In the case of the algorithms for Structural Health Monitoring, the knowledge of the behavior of a structure under different conditions allow to provide a hefty baseline [1]. In the particular case of the structures in-service, the variability in its dynamic properties can be a result of time-varying environmental and operational conditions [2]. Among the environmental conditions to bear in mind are humidity, wind loads, temperature, altitude, radiation, vibrations and pressure and for operational conditions it is necessary to consider loading conditions, operational speed and mass loading [2].

The design of methodologies to improve the damage identification including environmental and operational conditions is currently an area of active research interest. This interest is motivated by the fact that new designs in civil, aeronautics and astronautics include the use of more complex structures subjected to variable environmental and operational conditions. To assess the structural integrity it is necessary to have a reliable continuous monitoring that allows avoiding false alarms resulting from these variable conditions. Since a structure in normal operating conditions undergoes temperature variations and different forces by the environmental conditions, it is necessary to understand the effects of such conditions and test the developed methodologies under these conditions [11]. As contribution to the consideration of temperature in SHM systems, this work presents a methodology to detect damages by using an artificial immune system considering temperature variations. The methodology is based on the analysis of data from a piezoelectric active system which is permanently attached to the structure under test. The system works in different actuation phases and provide to the system the capability for obtaining some damage indices per each actuation phase and define the differences between the antibodies (healthy state) and the antigens (data from the structure under different structural states).

2 THEORETICAL BACKGROUND

2.1 Natural immune systems

The human immune system (HIS) is the body's defense system which is composed of a large network of specialized cells, tissues, and organs. The system further includes an elevated number of sensors and a high processing capability. The human immune system has proved its effectiveness in the detection of foreign elements by protecting the organism against diseases [4]. The principal skills of the human immune system are as follows [3], [11]:

(i) To discriminate between its own cells (self) and foreign cells (non-self);

(ii) To recognize different invaders (called antigens) in order to ensure the protection of the body;

(iii) To learn from specific antigens and adapt to them in order to improve the immune response to this kind of invader.

2.2 Artificial immune systems

Since the natural immune system has proved its effectiveness in the human body's defense, it can be used in the same way as a pattern recognition approach by means of a computational system. In the specific case of the SHM systems it can be used to discern differences between a healthy and a damaged structure [8]. Three immunological principles are used in artificial immune system [7], [6]:

-Immune network theory: This explains how the immune memory is built by means of the dynamic behavior of the immune system cells [5].

-The negative selection: The negative selection is a process that allows identifying and removing cells that react to the own body cells giving to the system a tolerance to own cells. This ensures a proper functioning of the immune system since it is able to distinguish between foreign molecules and self-molecules, avoiding autoimmune diseases [6].

-The clonal selection: This is a process of adaptive immune responses in which the cells of the system are adapted to identify an invader element [7].

3 DAMAGE DETECTION METHODOLOGY

The methodology includes the use of data from a piezoelectric active system which works in several actuation phases [9]. Each actuation phase defines one piezoelectric as actuator to apply the excitation signal and uses the rest of the transducers as sensors [10].

Two steps are defined in the damage detection process, first, signals form the healthy structure are acquired at different temperatures and organized in a matrix, after that, same experiments are applied to the structure under different conditions and the data is again organized in a matrix as is shown in Figure 1.

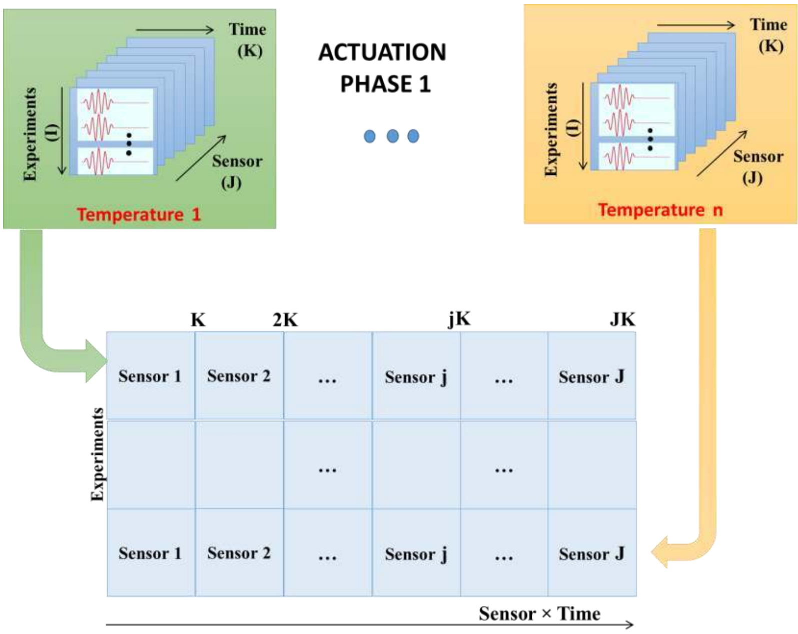

Figure 1: Data acquisition and organization.

To develop the artificial immune system, first, an organization is applied as it is shown in Figure 1. All data are pre-processed by group scaling [10] and the data from the healthy structure are used to develop the PCA model as in Figure 2. After that, an analysis of the cumulative variance is performed in order to determine the number of components to use. In the verification process, data from the structure in different states (damaged or not) are projected into the PCA models and the damage indices T^2 and Q are calculated. Using these indices the feature vectors are obtained per each actuation phase and a random selection is performed with data from the healthy structure to obtain the antibodies, these are evolved and used to define the pattern of the healthy structure. Damage detection can be obtained by applying the affinity measurement as is shown in Figure 3.

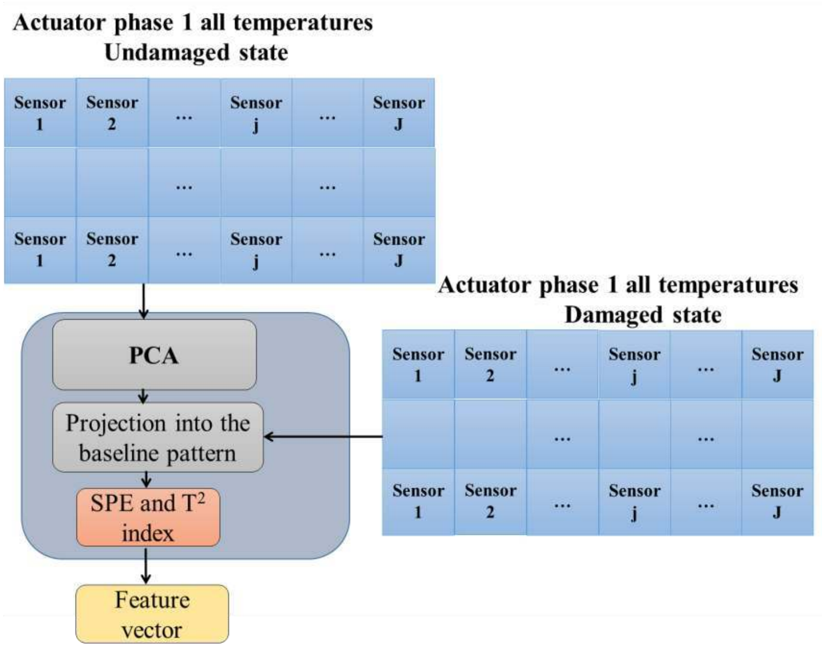

Figure 2: PCA modeling and damage detection index.

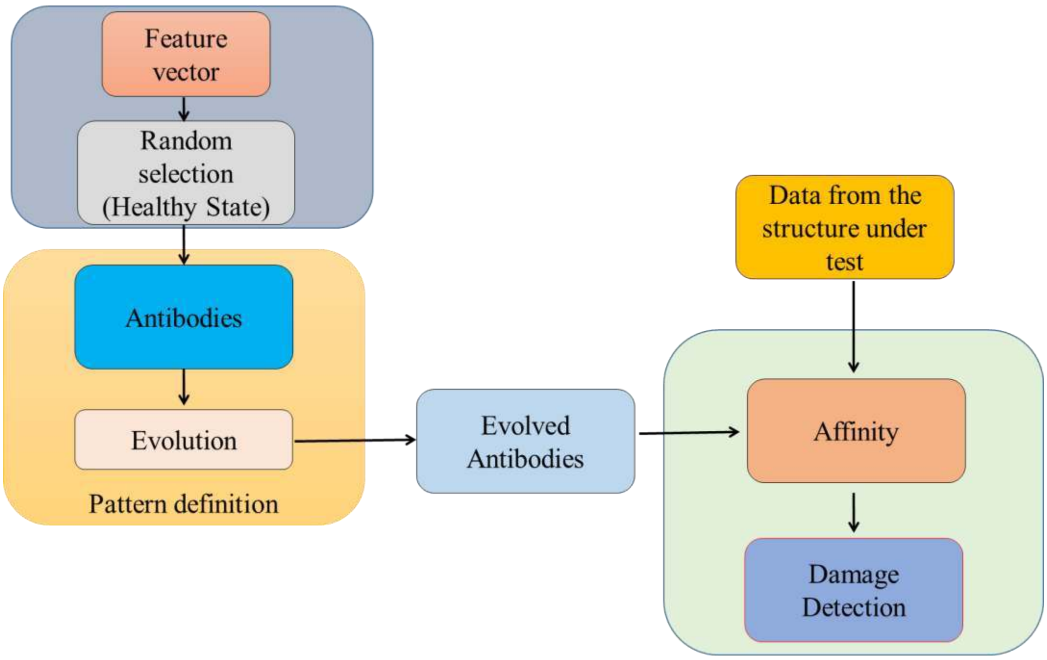

Figure 3: Damage detection process.

4 EXPERIMENTAL SETUP

To validate the methodology, an aluminium plate with dimensions 40 cm × 40 cm instrumented with 5 PZT transducers bonded on the surface is used as shown in Figure 4a. Six damages have been simulated on the structure by placing magnets on both sides of the structure at different positions between the sensors. To inspect the structure, a 12V Hanning windowed cosine train signal with 10 cycles and 10 KHz as central frequency was used. This structure was subjected to temperature changes. To perform these experiments, the structure was placed in an oven with controlled temperature. Data from the structure under six different temperatures (25ºC to 50ºC with increments of 5 ºC) for each structural state were collected.

a. b.

Figure 4: Aluminium plate and experimental setup.

5 EXPERIMENTAL RESULTS

Figures 5, 6 and 7 show the results obtained with the damage indices in the actuation phases 1, 2 and 5. The data in green color correspond to the data from the healthy structure and data in red are all the six damages, both dataset include results from all temperatures. Only three plots are included, however similar results are obtained in the rest of the actuation phases.

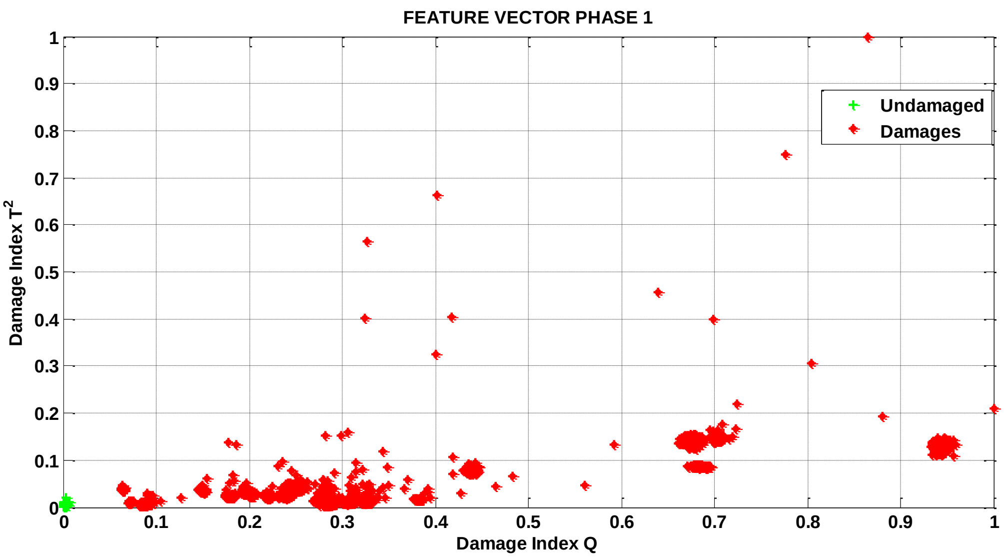

Figure 5: Damage index plot in the actuation phase 1

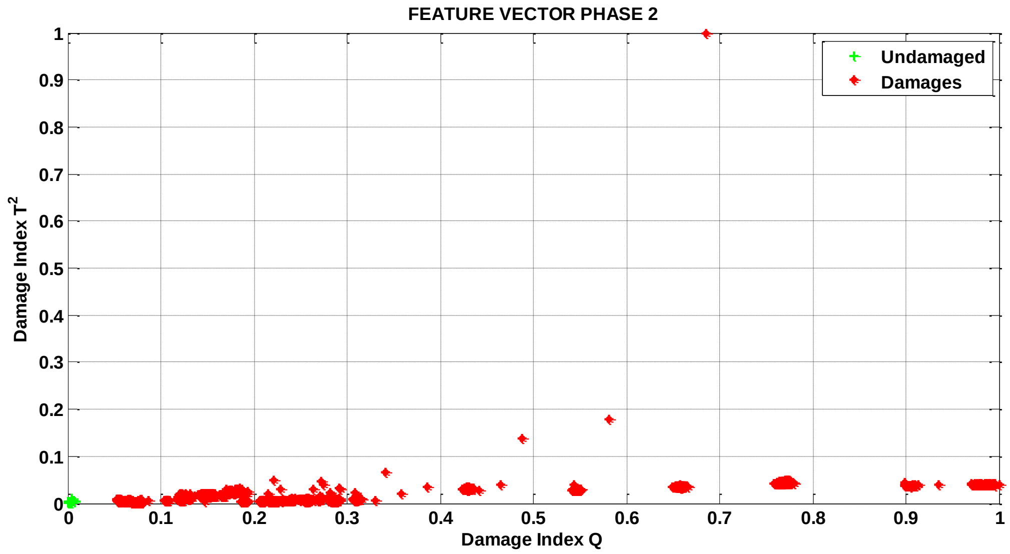

Figure 6: Damage index plot in the actuation phase 2.

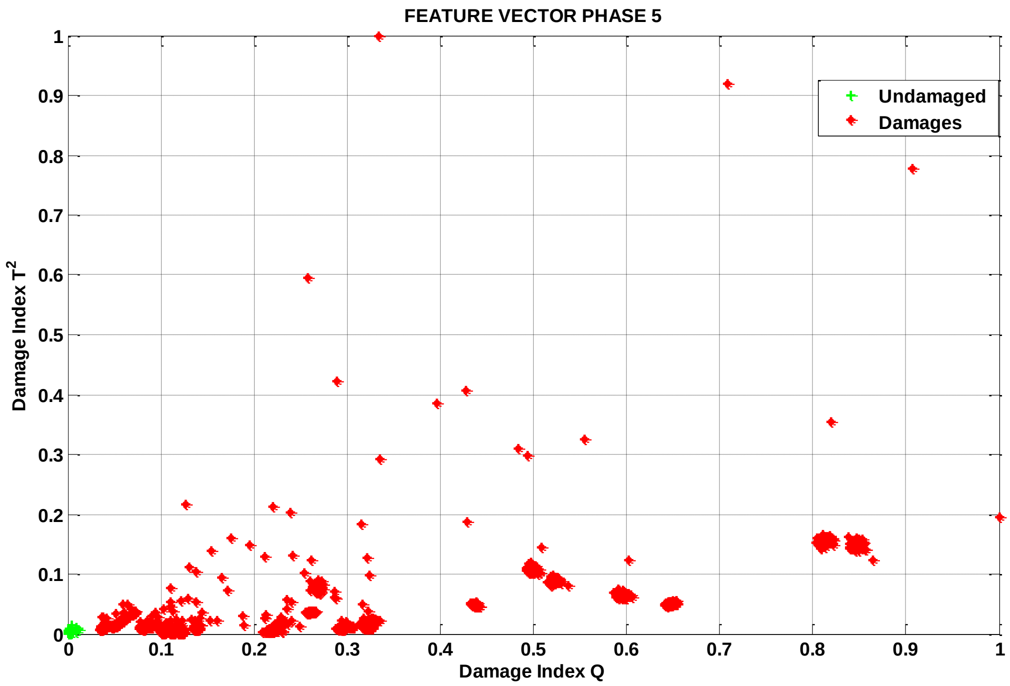

Figure 7: Damage index plot in the actuation phase 3

As it is possible to observe from the previous figures, there is a separation between data from undamaged structure and the structure with different damages. In previous works it was demonstrated that until this step it is possible to perform a damage detection process, however two indices need to be analyzed to determine the presence of damages which can be difficult if there is no clear separation between the data in the plots.

As next step in the methodology introduced in section 3, the antibodies are calculated to define the healthy pattern and new data from the unknown state of the structure are used as antigens to perform a comparison by means of the Euclidian distance and to define the affinity value. Figures 8, 9 and 10 shows the results in the affinity values in actuation phases 1, 2 and 5, similar results are obtained in the rest of the phases.

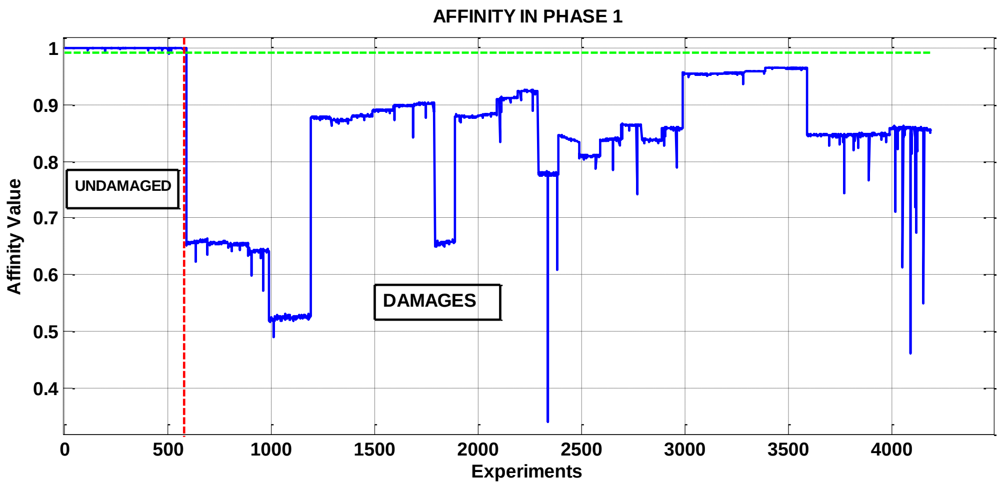

Figure 8: Affinity plot in the actuation phase 1.

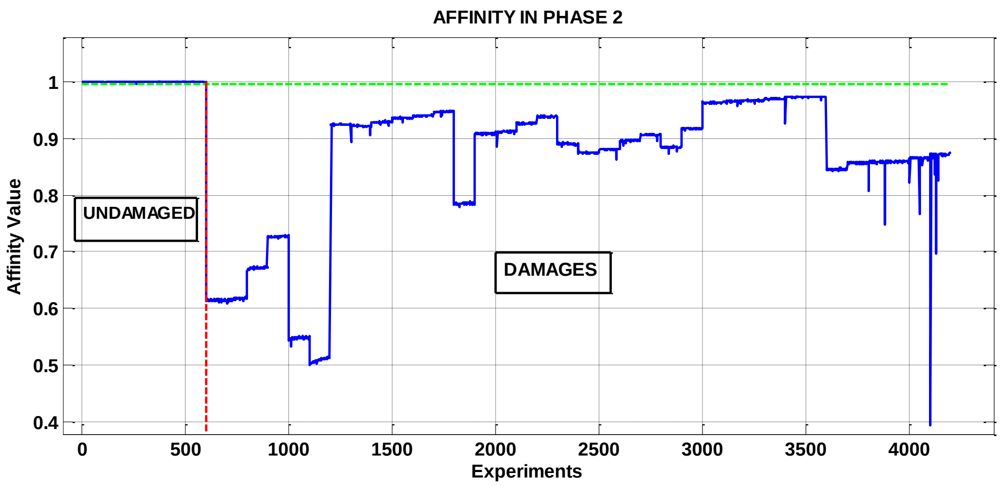

Figure 9: Affinity plot in the actuation phase 2.

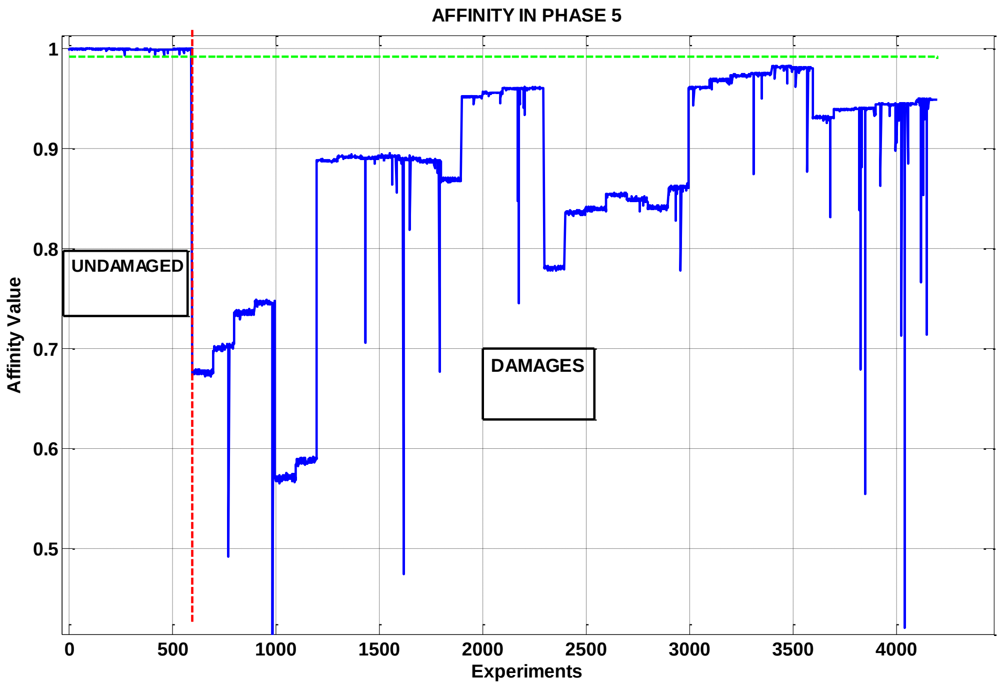

Figure 10: Affinity plot in the actuation phase 5

By performing an analysis to the affinity plots, it is possible to observe that each damage is perceived differently to the healthy state. In addition, all the structural states present differences in the affinity value, consequently they can be used in a future together with a classifier to classify the damages.

6 CONCLUSIONS

Changes in the temperature result in changes in the signals propagated through the structure and in the way in which the signals collected by the sensors are interpreted by the damage detection algorithms, by this reason it is necessary to develop algorithms that include the effects of temperature changes. Results obtained with the introduced methodology showed that it is possible to detect damages in the structure under test, in spite of the changes in the temperature.

The use of the affinity value allows to reduce the number of variables to analyze in the damage detection process and provides information about the similarity of each structural state with the healthy state and between them. Finally, it is necessary to conclude that the use of robust baselines as the presented in this paper allows to obtain a clear separation between the healthy state and the damage states by means of the affinity value in all the evaluated cases. Since each structural state have a different affinity, the method shows potential for using in a classification approaches.

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