Damage Identification using Soft-computing Techniques

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1 INTRODUCTION

The damage identification problem in structural analysis is usually based on the phenomenon of elastic strain wave propagation. An excitation signal is applied and the dynamic response is examined. Many works analyses the perturbations to the original signal due to structural damage. However the currently used methods encounter problems with obtaining the proper solution to damage identification and the related numerical cost is considerable.

We propose an approach using Case-Based Reasoning (CBR), Self Organizing Maps (SOM) and Wavelet Transform (WT) in order to obtain an initial diagnostic exploiting the data generated by the modeling structure and the data acquired by the sensors once the system has started, creating an incremental database (since a new experience is retained each time a problem has been solved) in order to use in diagnosing future situations by analogy.

2 CASE BASED REASONING

Reasoning based on experience is a powerful procedure frequently used by human beings to solve problems, both in day-to-day life and in situations requiring more expertise. People rely on similar previous experience when they need to solve a problem, reusing solutions without thinking about the situation so much. . In any field, when tackling problem, a professional with many years of experience is generally considered to be more suitable than a recent graduate with brilliant grades. Daily life continually presents opportunities to apply case based reasoning. CBR systems, instead of being exclusively based on general knowledge of the domain of a problem or establishing associations through a set of generalized relations among descriptors of problems and conclusions, use the specific knowledge of previous experiences in concrete situations. To reach that goal, CBR methodology proposes the cycle of the 4 R's (see Figure 1) [2][4].

Retrieve the most similar cases (a new problem is grouped with other similar problems saved in a case-base)

Reuse the solutions proposed in the cases to solve the problem

Revise the proposed solution (if necessary)

Retain the new solution as a part of a new case once it has been confirmed or validated

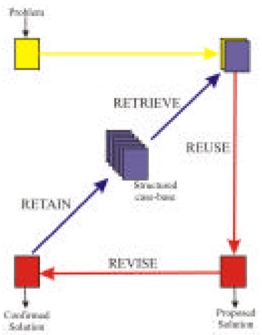

Figure 1. Conventional CBR cycle

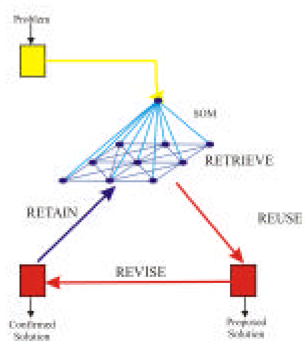

Figure 2. Purposed CBR cycle

3 SELF ORGANIZING MAPS

Self-Organizing Maps (SOM) are the largest representation of artificial neural networks. An SOM is a classifier that can be visualized as a two-dimensional neural network arrangement. The principle used by Kohonen [1] to develop the self-organizing maps is based on the organization of neurons according to the features of the received stimulus. The greatest strength of the self-organizing maps lies in the possibilities they have to model and analyze complex experimental data vectors. The self-organizing maps are non-linear projection methods from a high-dimensional input space to a bi-dimensional space, where it is easier to classify and visualize as vectors. The reduction in the number of dimensions could permit the visualization of important relations between the data that would not be appreciated in any other way.

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4 WAVELET TRANSFORM

A wavelet transform is similar to a Fourier transform. The Fourier transform the signal is broken up or decomposed into sine waves of various frequencies. The Wavelet transform is the procedure by which a signal is broken up in a sum of translations (shifting) and dilations (scaling) of a function, called *mother wavelet.* The continuous wavelet transform (CWT) is defined as the sum over all time of the signal multiplied by scaled, shifted versions of the wavelet function ψ:

$$C(scale, position) = \int_{-\infty}^{\infty} f(t)\Psi(scale, position, t)dt$$

The result of the CWT is many wavelet coefficients C, which are a function of scale and position (see Figure 3). Multiplying each coefficient by the appropriately scaled and shifted wavelet yields the constituent wavelets of the original signal.

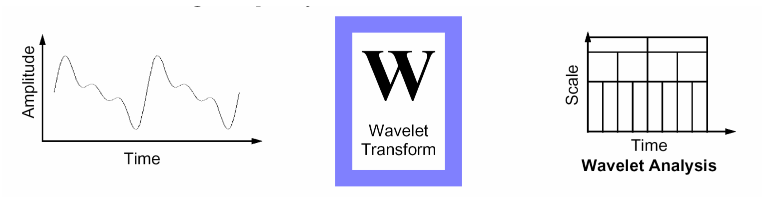


Figure 3. Wavelet Transform

In wavelet-based feature extraction for signal interpretation, the wavelet coefficients are grouped into clusters in an unsupervised mode. The procedure divides the scheme of all computed wavelet coefficients into disjoint clusters $U_1, U_2, \ldots, U_c$ for each of which a single robust feature u_i $(i = 1, 2, \ldots, c)$ can be computed. The so obtained feature vector $(u_1, u_2, \ldots, u_c)$ serves as an input pattern to a signal interpretation procedure such as a neural network [3].

5 ORIGINAL CONTRIBUTION

5.1 HOW IS DAMAGE IDENTIFIED?

We propose using Case-Based Reasoning methodology in damage detection, taking advantage of experience and the model of the structure, exploiting the data acquired by sensors in real practice and the outcomes given in known models simulations. The goal is to use Soft Computing techniques (SOM,WT) to relate the data stored in the memory with representative situations as cases to be used in a later diagnosis by analogy.

Bearing in mind that Case-Based Reasoning is a methodology [5], Figure 2 shows our CBR system, it has a casebase that consists of a Self-Organizing Map. For each new case, the SOM retrieves the group of old cases with same features. These features are extracted using Wavelet Analysis [3].

5.2 OUR APPROACH APPLIED IN A TRUSS STRUCTURE

5.2.1 Description

Figure 4 shows a cantilever truss structure to be considered. Materials and geometric specifications have previously been assigned. The opposite sine excitation to the phase is applied to elements 36 and 38. Member 1 was chosen as the sensor receiving the propagated wave.

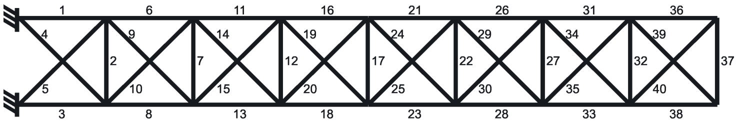


Figure 4. Cantilever Structure

5.2.2 How to build cases?

A case is defined by defect in the structure and the principal features of the elastic wave either modeled or detected by the sensor. For example we have a case with damage in the element 13, the elastic wave is shown in Figure 5 and the principal features in the Figure 6.

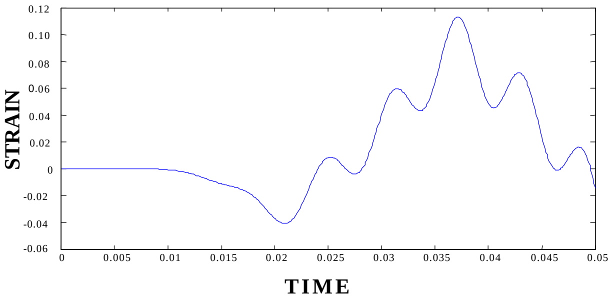


Figure 5. Elastic wave detected

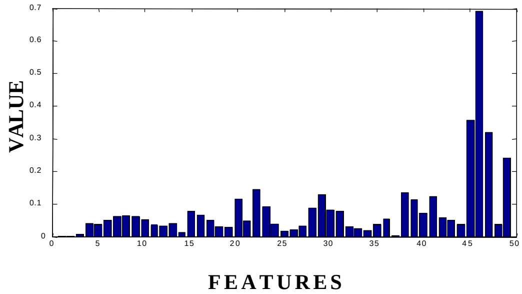


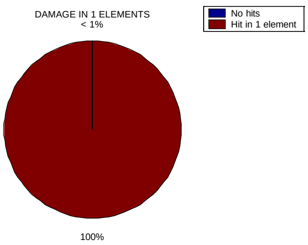
Figure 6. Principal features of the wave

5.2.3 How should the solution be retrieved?

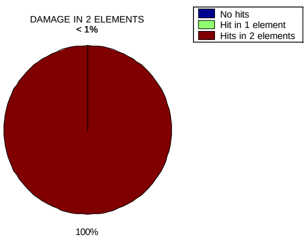
In this way, when a new case is occurred, we don't know the damage, but we have its principal features, The SOM retrieve a set of old cases with most similar features, from this set we propose a solution (its damage). When this solution is validated, it is stored like a new case into the SOM.

5.2.4 Outcomes presentation

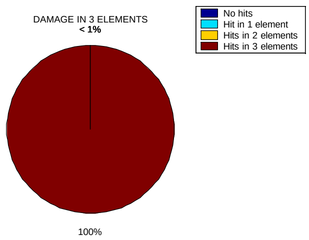
In order to build the casebase, it is necessary to generate damage patterns and to obtain the elastic wave simulated or detected by sensor. Taking into account of the structure in the previous example, we have generated cases of simultaneous damage of 1,2,3,4 and 5 elements into casebase. So as to evaluate the approach, we have generated tests of simultaneous damage of 1,2,3,4,5,6,7,8 and 9 elements. The following figures show the percentage of accurate detections of each test divided by the number of detected defective elements. For example the picture with 6 defective elements Figure 7f, we are detected 3 defectives elements from 6 (hit in 3 elements) in the 14% of the cases, and we are detected 4 elements from 6 (hit in 4 elements) in the 39%.



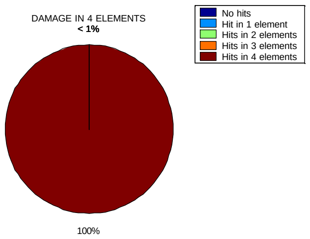
a. Damage in 1 element



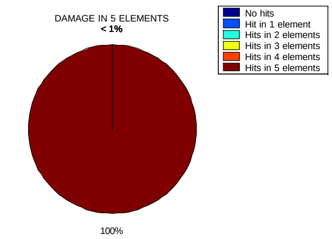
b. Damage in 2 element



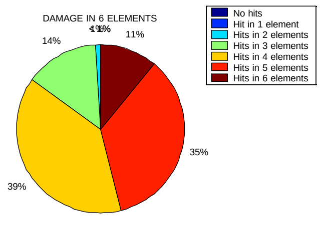
c. Damage in 3 element



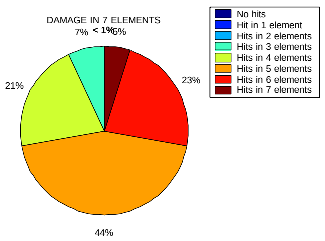
d. Damage in 4 element



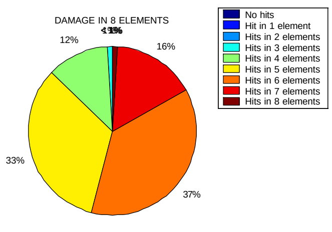
e. Damage in 5 element



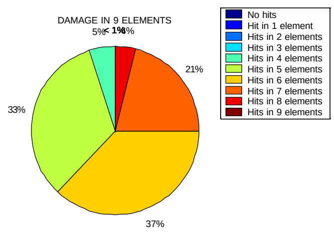
f. Damage in 6 element



g. Damage in 7 element



h. Damage in 8 element



i. Damage in 9 element

Figure 7. Accurate detections in each test

5.2.5 Outcomes analysis

The casebase includes damages up to 5 horizontal elements, therefore up to 5 defective horizontal elements are totally detected (100%). If there are damages too much of 5 elements, it isn't detected completely, however the system adapts the solution and it is able to detect up 8 and 9 defective elements, although still in low percentage.

6 CONCLUSIONS

There are several advantages to the CBR systems approach using SOM. It most closely resembles the human decision making process. This means that it does not require a complete set of data in order to solve a problem. The knowledge is stored in memory as separate "cases" defined only by the defect in the structure, this is important because it allows fast construction of a knowledge base. It also allows for easier system maintenance because new cases can easily be entered into memory and old cases can be totally revised or deleted.

The ability of the CBR system to provide a quick answer is also desirable. The system indexes important information in the case and looks for a similar case. If there is an exact case in the knowledge base, almost instantaneously the solution can be displayed and implemented.

It is very important to determine which are the real damages presented in the structure, coherent and logical damages. In fact the system is able to train with a lot of cases (infinite), however in practice it is not certain, due to storage limitations. Therefore, it is not appropriate to load the system with damages that never will happen.

The main value or innovation of this system is the exploitation of the model of the structure to pre-load the casebase. In this way, when the system is put in operating mode, it is able to detect damages given a very good performance even before loading any real damage in the casebase.

7 REFERENCES

[1] Kohonen, T.: 1990 "The Self – Organizing Map", Proceedings IEEE, vol 78, No 9.

[2] Lopez de Mantaras, R; Plaza, E.: 1997. "Case-Based Reasoning: An Overview". AI Communications Vol. 10(1), pp 21-29

[3] Pittner, S., Kamarthi, S.V.: "Feature extraction from wavelet coefficients for pattern recognition tasks". Pattern Analysis and Machine Intelligence, IEEE Transactions on, Volume: 21 Issue: 1, pp. 83-88 (1999)

[4] Watson I.: 1995, "An introduction to case-based reasoning". Springer-Verlag,

[5] Watson I.: 1998, "CBR is a Methodology not a Technology". In, Research & Development in Expert Systems XV. Miles,R., Moulton, M. & Bramer, M. (Eds), pp 213-223. Springer-London. ISBN 1-85233-086-4