Improved Genetic Algorithm for Structural Damage Detection

Jose E. Laier[1*] and Jesus D.V. Morales[1]

Department of Structural Engineering, Engineering School of São Carlos, University of São Paulo, 13566-590 São Carlos, Brazil

Abstract. Structural damage detection consists of determining the location and severity of damage in civil structures by using measured parameters. Genetic algorithm is a meta-heuristic computing method for finding approximated global minimums in large optimization problems and has the advantage of probabilistic hill climbing. In this work the improved genetic algorithm is employed to solve damage detection problem in truss type structures using vibration data (natural frequencies and mode shapes). The formulation of the objective function for the optimization procedure is based on natural frequency and vibration mode shapes. Present structural damage-identification scheme is confirmed and assessed using a Finite Element Model formulation (FEM) of truss structure. Results are presented in tables.

Keywords: genetic algorithm, vibration parameters, damage detection

1 Introduction

As already well established, the methods for structural assessment from dynamic responses can be classified in two groups in accordance with its dependence on a structural model: the methods based on signals (experimental method) is the first one and the second are the methods based on finite element models (Zou et al., 2000).

Novelty Detection (Worden et al., 2002) is a typical signal based method, whose principal objective is to extract features from dynamic data that characterize the state of the structure. This technique permits only to detect the damage in the lowest level that is to decide whether the damage occurred. The other methods based signals as Eddy's currents technique, acoustic emission, X rays, ultrasonic methods, thermal and magnetic field methods and visual inspection (Goch et al., 1999) need an a priori knowledge of damage's location and that the access to any

* Corresponding author, e-mail: jelaier@sc.usp.br

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part of the structure be available. More than these limitations, these methods can only permit to detect damage near the structure's surface and work relatively well in small size structures. The advantages of these methods are that they avoid modelling errors and time consuming computational calculations. However, these methods are inefficient when applied to large structural systems, for which the techniques based in the structure's dynamic response are promising due its global character.

In this paper, an improved genetic optimization algorithm using real code version is developed to solve structural damage detection problems; that is, determining the location and severity of damage by using dynamic measured characteristics (natural frequencies and corresponding mode shapes). The formulation of the objective function for the optimization is based on the natural frequencies and mode shapes obtained by using a classical Finite Element Model of truss structures. In order to study the structural damage detection the damage is considered by a reduction in stiffness at the damaged location on the structure.

2 Theoretical Backgrounds

When a damage event has occurred in the structure, the stiffness matrix will change and consequently, the natural frequencies and mode shapes will change. Assuming that the mass and damping matrices are constant (not affected by the damage) the stiffness of the k^{th} damaged element is given by:

$$[K]_k^d = \alpha_k [K]_k \tag{1}$$

in which $0 \leq \alpha_k \leq 1$ is a damage variable: the value of unity indicates that the element is undamaged whereas a damage element would cause the stiffness reduction factor for that location to take on a fractional value (decrease in modulus of elasticity) or zero, and constitutes the design variables of our problem; d as exponent indicates damaged element. Notation $[K]_k$ indicates the stiffness matrix of the k^{th} undamaged element.

The equation of motion for the structural system under free vibration can be written as:

$$[M]\{\ddot{u}\} + [K]\{u\} = \{0\} \tag{2}$$

where $\left[M\right]$, and $\left[K\right]=\sum_{k=1}^{p}\left[K\right]_{k}^{d}$ are the structure mass and stiffness matrices, respectively, p is the number of elements in the finite element model, $\left\{u\right\}$ is the vector of the displacements. Assuming the undamped free vibration solution for equation (2), one has

$$\left(\left[K\right]-\omega^{2}\left[M\right]\right)\left\{u\right\}=\left\{0\right\} \tag{3}$$

where ω is the eigen-value and $\left\{u\right\}$ is the eigen-vector.

In this paper the objective function is based on the following expression

$$F=\sum_{1}^{nm}\left|\frac{\omega_{j}^{ga}-\omega_{j}^{ex}}{\omega_{j}^{ex}}\right|+W\sum_{1}^{nm}\sqrt{\frac{\sum_{1}^{nc}\left(u_{ij}^{ga}-u_{ij}^{ex}\right)^{2}}{\sum_{1}^{nc}\left(u_{ij}^{ex}\right)^{2}}} \tag{4}$$

where $nm = 8$ refers to number of vibration modes considered, superscript ga refers to finite element model results using the genetic algorithm, superscript ex indicates experimental results, ω_{j}^{ga} and ω_{j}^{ex} are the natural frequency of the finite element model and corresponding experimental one, respectively; u_{ij}^{ga} and u_{ij}^{ex} are the ith mode shape magnitude of the degree j and $W = 0.1$ is the weight factor. It is important to note that this objective function takes into account a combination involving natural frequency and mode shapes. Since the measured mode shapes are less accurate than natural frequencies, the weight of the mode shapes is usually of an small magnitude. The objective function to be maximized by using genetic algorithm is given by

$$G_{obj}=\frac{c_{1}}{c_{2}+F} \tag{5}$$

where c_1=20000 and c_2=1 are adopted constants.

3 Real-Coded Genetic Algorithms

Genetic Algorithms are based on principles of evolutionary theory such as natural selection and evolution (Mares and Surace 1996). In this paper only the improved version of the real-coded Genetic Algorithm is briefly introduced.

The term chromosome refers to a candidate solution to a defined problem, fitness is the objective function and the gene is component of the chromosome. The proposed genetic algorithm starts with an initial randomly generated population of 100 chromosomes, namely $x_1, x_2..., x_{100}$. The length of each chromosome is the dimension of the solution space, ie: $x_i = \left[\alpha_1, \alpha_2..., \alpha_m\right]$, where m is the number of element (bars) on structure. As in most practical case the damage occurs in one or two elements, in order to generate the initial population the following heuristic is adopted: if $rand\left[0-1\right] \leq 0.4$ one consider $\alpha_i = rand\left[0-0.6\right]$, if not it is assumed $\alpha_1 = 0$ (undamaged).

Selection is a process in which individual chromosomes are chosen according to their fitness. The chromosomes with a higher fitness have a higher probability to survive in the next generation. The selection is performed using Tournament operator with n=2 (Goldberg and Deb 1991). The crossover is implemented using BLX-α technique (Eshelman et al. 1993) with α=0.5 and crossover probability of 0.9 (90%). If no crossover takes place, the two off-springs are exact copies of their respective parents. Random mutation is implemented using mutation probability of 0.05 (5%). The final operation is that of elitism, which consists to reproduce in the new generation the best member of the preceding generation.

Good results are obtained applying the following heuristic: after 300 generation the gene whose damage is lower than 5% is considered undamaged and re-start the process. This is done in order to improve the final result. It is known that the light damage elements are not correct and their presence do not permit the convergence to the exact damage scenario.

4 Numerical Example

As numerical simulation it is considered the finite element model of the truss-type structure illustrated in figure 1 (Mares and Surace1996). This structure has twenty one degrees-of-freedom, each member in the truss having the following characteristics: modulus of elasticity E=7.03 x 10^{10} N/m^2; density $\rho = 2685$ kg/m^3; cross sectional area A=0.001 m^2; length of each bay $\ell = 0.75$ m.

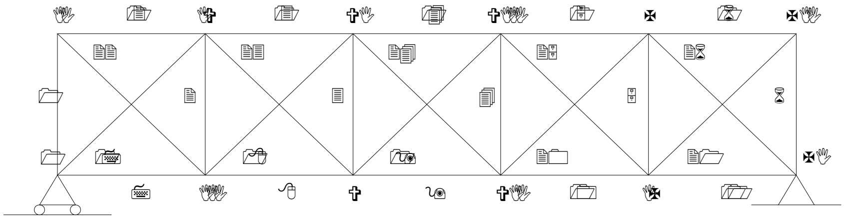

Figure 1. Five-bay truss structure.

The damage scenario considered is given taking into account partial damage of 70% ($\alpha = 0.7$) on members 2, 8 and 23. In this problem, in order to simulate an experimental analysis, random noise given by $0.01 rand\left[-1,1\right]\omega_j$ and $0.03 rand\left[-1,1\right]\phi_{ij}$ is added to the values of the natural frequencies and mode shapes respectively.

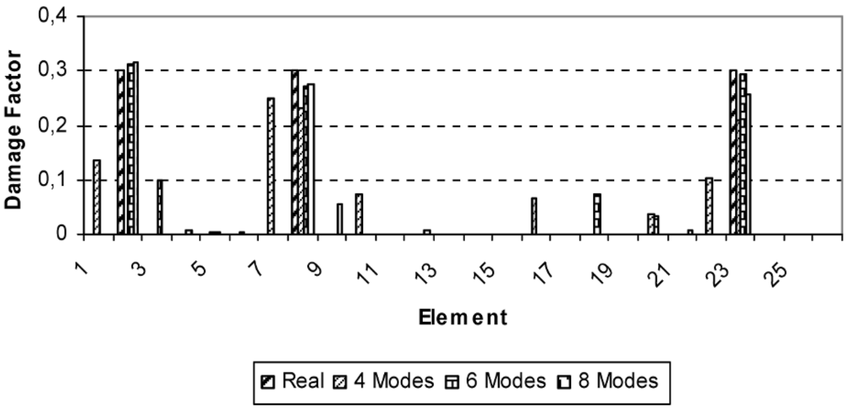

Figure 2. Identified stiffness reduction factor

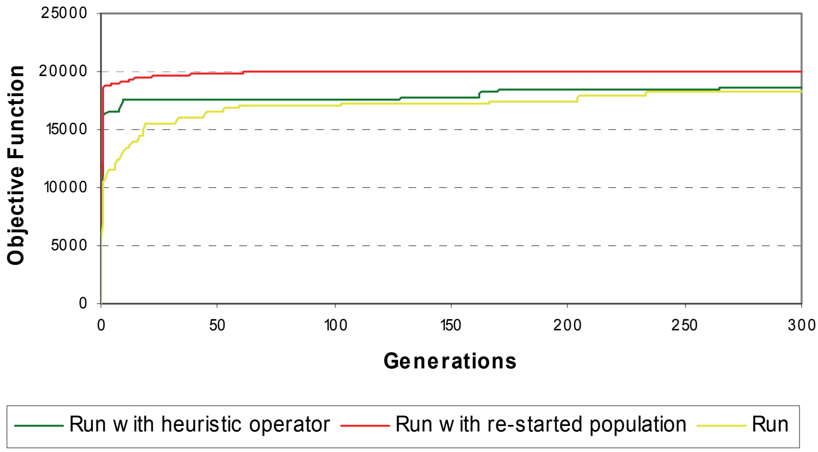

Figure 3. Objective function

Figure 2 shows the results obtained. It is important to note that when 4 modes are used it is not possible to identify correctly the damage scenario. But when 6 modes are considered all three damaged element are captured although the damage of the element 3 is not correct (10%). Good results are clearly obtained using 8 modes. Figure 3 depict the fitness evolution of the best member. One can observe that the proposed heuristic operators are very efficient.

5 Conclusions

A genetic algorithm with real number coding is applied to solve the structural damage detection by using free vibration parameters. Numerical results indicate that the proposed heuristics gives better damage detection than the conventional optimization methods.

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