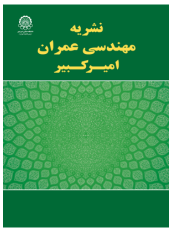

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Damage Detection Based on Modal Parameters and Dynamic Responses using by Enhanced Grey Wolf Optimization

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ABSTRACT: Structural damage causes a reduction in stiffness of some elements of structure and gives rise to some changes in structures' modal parameters (natural frequencies, mode shapes, etc.) and dynamic responses (acceleration, velocity, and displacement). Hence, intact structures' data is different from damaged structures' data and can be used to detect structural damages. Many techniques are recently utilized to facilitate damage detection, some salient examples of which are non-destructive methods and using of structure responses. The main purpose of this paper is to present a method for estimating structural damage detection based on the measurement of modal parameters and comparing its results with results of measurement of dynamic responses in a limited number of degrees of freedom. To detect the damage, two objective functions have been defined: one with modal parameters and the other one with structural dynamic responses data. For optimizing the objective functions, a new hybrid algorithm including GWO and PSO has been designed and its results have been compared to GA and PSO. Two examples including a ten-story shear building and a ten-element truss are considered and the efficiency of the proposed strategy in damage detection is assessed. The results indicate that the proposed strategy has acceptable performance.

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1. Introduction

Damages to the elements of a structure may be caused by sudden incidents, such as earthquakes or high winds, or maybe gradually occurred due to deterioration and bad maintenance [1, 2]. The main purpose of this paper is to present a new method for estimating structural damages based on the measurement of modal parameters or system's response and comparing them with the supposed response of the undamaged structure. To detect damages in civil structures two objective functions have been defined: one with modal parameters and the other one with the measured acceleration of the roof. To minimize the objective functions, a new hybrid algorithm based on Gray Wolf Optimization (GWO) and Particle Swarm Optimization (PSO) is proposed. The performance of this method in damage identification is compared to the Genetic Algorithm (GA) and PSO.

2. Proposed Method for Damage Detection Problem

The modal properties of a structure are found from the following eigenvalue problem:

$$K\phi_i - \omega_i^2 M\phi_i = 0 \tag{1}$$

When an element of the structure is damaged, its stiffness is changed as Eq. (2). Here $d_e \in [0,+1]$ denotes the damage index.

$$k_d^e = k^e(1-d_e) \tag{2}$$

The values of the damage indices are found by a smart trial and error procedure. First, a set of estimated values for the damage indices are assumed. Then, the response of the structure is computed for those indices. Next, that response is compared with the real measured response of the structure. This is performed by the objective function. A smaller value of the objective function means that the estimated indices are close to their real value. Based on the objective function's value the estimations of the indices are updated. This procedure is continued until the desired accuracy is reached. Objective Eqs. (3) and (4) are used in this study. They are defined using the natural frequencies and the measured acceleration of the roof.

$$f_1 = \sum_{i=1}^{N} \left|\omega_{m,i} - \omega_{c,i}\right| / \left|\omega_{m,i}\right| \tag{3}$$

$$f_2 = \left(\int_{t=0}^{T} \left|a_m - a_c\right| \,\mathrm{dt}\right) / \left(\int_{t=0}^{T} \left|a_m\right| \,\mathrm{dt}\right) \tag{4}$$

The damage indices are estimated by searching for a minimal solution of the objective functions. For this purpose, a new hybrid of Gray Wolf Optimization algorithm (GWO) and Particle Swarm Optimization (PSO) is presented in this study.

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2.1. Particle Swarm Optimization Algorithm

This algorithm [3] can be summarized as follows:

1) Generate the initial population and evaluate its fitness using the objective function.

2) Determine best-so-far solutions.

3) Update locations and velocities of the new solutions.

4) Iterate the above steps until the desired termination condition is met. The required equations are summarized below:

$$x_i = [x_{i1}, x_{i2}, ..., x_{iD}] \tag{5}$$

$$X = \{x_1, x_2, ..., x_N\} \tag{6}$$

$$x_i(t+1) = x_i(t) + v_i(t+1) \tag{7}$$

$$v_i(t+1) = w\upsilon_i(t) + r_1 c_1 (p_i(t) - x_i(t)) + r_2 c_2 (p_g(t) - x_i(t)) \tag{8}$$

$$w = w_{max} - (w_{max} - w_{min}) \times t / T \tag{9}$$

2.2. Gray Wolf Optimization Algorithm

The first, second, and third best solutions are labeled as α, β, and δ. The rest proper solutions are labeled as γ. The required equations for generating new solutions are summarized below:

$$\vec{D} = |\vec{C}.\vec{X}_p(t) - \vec{X}(t)| \tag{10}$$

$$\vec{X}(t+1) = \vec{X}_p(t) - \vec{A}.\vec{D} \tag{11}$$

$$\vec{A} = 2\vec{a}.\vec{r}_1 - \vec{a} \tag{12}$$

$$\vec{C} = 2.\vec{r}_2 \tag{13}$$

$$\vec{D}_\alpha = |\vec{C}_1.\vec{X}_\alpha - \vec{X}|, \vec{D}_\beta = |\vec{C}_2.\vec{X}_\beta - \vec{X}|, \vec{D}_\delta = |\vec{C}_3.\vec{X}_\delta - \vec{X}| \tag{14}$$

$$\vec{X}_1 = \vec{X}_\alpha - \vec{A}_1.(\vec{D}_\alpha), \vec{X}_2 = \vec{X}_\beta - \vec{A}_2.(\vec{D}_\beta), \vec{X}_3 = \vec{X}_\delta - \vec{A}_3.(\vec{D}_\delta) \tag{15}$$

$$\vec{X}(t+1) = (\vec{X}_1 + \vec{X}_2 + \vec{X}_3)/3 \tag{16}$$

2.3. Proposed Algorithm (GW-PS)

Fig. 1 presents the flowchart of the proposed algorithm. It is named GW-PS and is based on the Gray Wolf Optimization Algorithm enhanced by elements from the Particle Swarm Optimization algorithm.

3. Numerical Example

A 10-story building is subjected to El Centro (1940) earthquake and undergoes structural damages.

The objective function values and the good performance of the proposed method (GW-PS) in the identification of the damage index on the 4th floor, in comparison with Genetic Algorithm (GA) and PSO, are presented in Figs. 2 and 3.

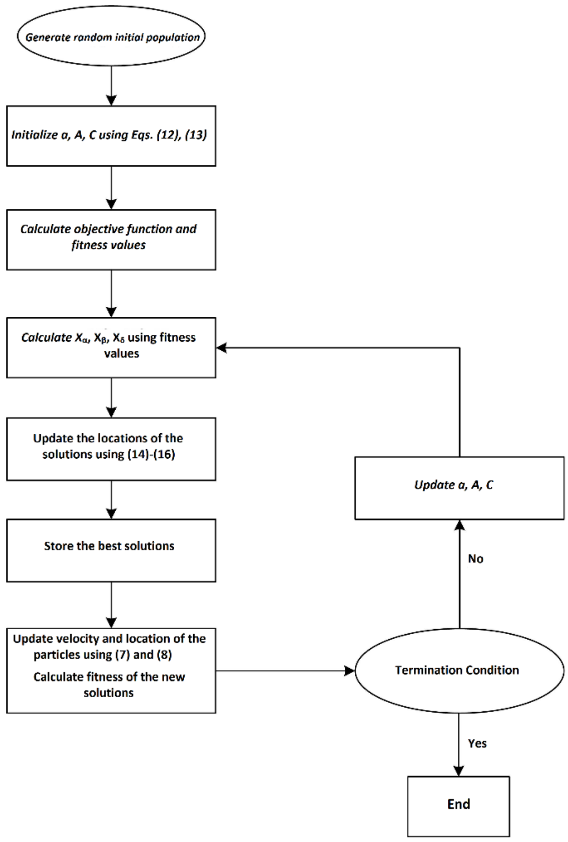

Fig. 1. Flowchart of the proposed damage detection method (GW-PS).

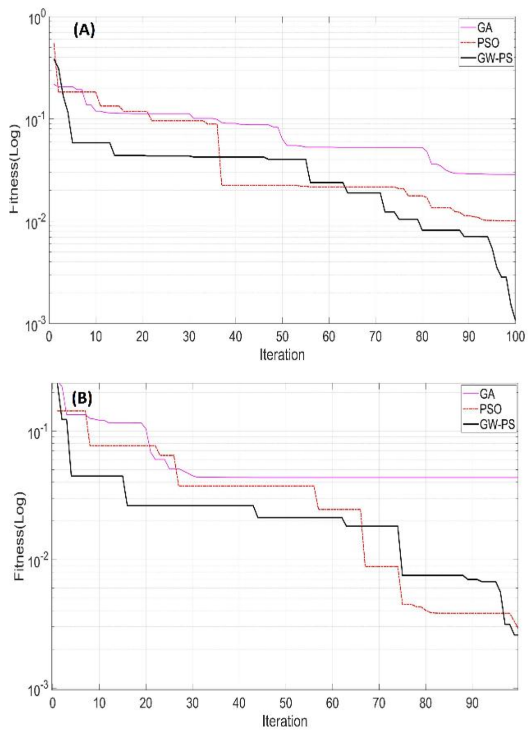

Fig. 2. Fitness values calculated from: A) Modal data. B) Measured acceleration data.

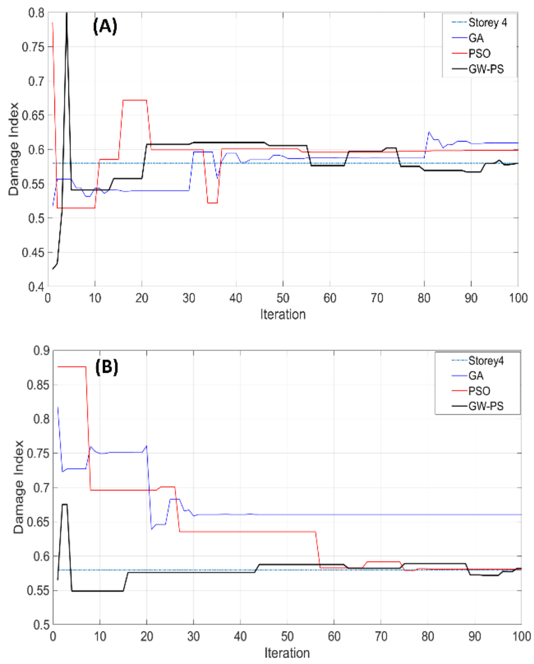

Fig. 3. The estimated damage index on the 4th floor is calculated from A) Modal data. B) Measured acceleration data.

4. Conclusions

A new method for structural damage detection based on measurement of modal parameters and comparing its results with measurement of dynamic responses in a limited number of degrees of freedom is proposed. The method is based on the Gray Wolf Optimization and Particle Swarm Optimization algorithms. The provided numerical simulations show the good performance of the proposed method in comparison with the other well-known methods such as Genetic Algorithm and Particle Swarm Optimization.

References

[1] C. Ghee Koh, L. Ming See, T. Balendra, Damage detection of buildings: numerical and experimental studies, Journal of structural engineering, 121(8) (1995) 1155-1160.

[2] A. Rytter, Vibrational based inspection of civil engineering structures, Dept. of Building Technology and Structural Engineering, Aalborg University, 1993.

[3] R.Eberhart,J.Kennedy,Particleswarmoptimization, in: Proceedings of the IEEE international conference on neural networks, Citeseer, 1995, pp. 1942-1948.

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