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Placing Sensors Optimally In Structures By Combining Mse Method With Aga For Structural Health Monitoring

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ABSTRACT
In the recent years, the wide range of engineering technology emerged in many fields like medical, transportation, industries, electronics and in any of structural systems etc. Among these fields their infrastructure and the built environment is the most important things to consider for ensuring safety. To properly manage these infrastructure of any fields, its condition or serviceability must be assessed and to be monitored. Nowadays, with the rapid development in technologies a sophisticated sensor usage in all fields is increased to monitor the condition of these structures and it can be achieved with the help of Structural Health Monitoring (SHM) systems. Considering cost, reliable data, accuracy of results, and computation time into account the proper deployment of sensor optimization becoming a challenging task in SHM. To make optimal placement in SHM a hybrid optimization strategy named MSE-AGA (Modal Strain Energy – Adaptive Genetic Algorithm) is proposed in this paper. The proposed approach first place the initial sensor location by using MSE. Second the obtained locations are optimized by using AGA. Three storey building structure is taken as contrast experiment in this paper for numerical analysis and also to place optimal number of sensors.

KEYWORDS:

INTRODUCTION

Many innovative real structures such as bridges, towers, tunnels, roads high-rise buildings have been built all over the world. These structures are easily harmed due to the natural disaster or by manmade changes [1]. However the traditional routine visual inspection method could be a useful tool, it is not currently effective to monitor the health of common structures due to the high cost, computation time and flexibility. And also the periodical observation of dynamic response measurements from sensors to determine the condition of the structure can be periodically changed in this method. So to assess the structural ability and performance of the aging structures without manual errors, we may need the SHM systems and also to detect damage. The damage is usually indicated in terms of the modal properties, in particular natural frequencies and mode shapes that could be obtained either from the data acquired during vibration tests or by finite element modal analysis [2]. SHM is the process of observation of the structural condition to protect the structures before extreme damage occurs. So any dynamic behavior or changes of the structures is determined with SHM systems [3]. For this type of monitoring, sensors play a key role in SHM to recover the faults. Generally more sensors are placed to gather more information but considering the cost and computation time limited sensors are deployed. In SHM deployment of sensors in the structures become an important part because the cost effective selection of the optimal number and location from the resulting measured data of sensors are most informative for estimating the parameters of a mathematical model of the structures. This method is known as optimal sensor placement

(OSP). By placing optimal number of sensors in the structures we can find the information about the structures in limited time, low cost and high efficiency. At present, sensor placement optimization algorithms can be generally divided into traditional algorithm and non-traditional algorithm. In past few years many non-traditional technology have been developed to achieve OSP mainly include a review concerning the differences and relationships of the sensor placement methods was provided by Yi and Li[4], Kammer [5] presented an effective independence (EI) method in which a number of candidate sensor positions are eliminated or added according to their ranks evaluated by the determinant of a Fisher information matrix (FIM) criterion, Li et al.[6] determined the existence of a relationship between the effective independence method & the modal kinetic energy method and presented a quick computation of the effective independence method through QR downdating, Carne and Dohrmann [7] proposed the OSP method for the parametric identification with the modal vector minMAC. All of these algorithms have their own limitations so we go for traditional algorithm such as simulated annealing method [8], Particle Swarm Optimization algorithm and Genetic algorithm (GA). Among the above-mentioned heuristic algorithms, the GA has been proposed by several subsequent investigators [9] for optimal sensor placement. GA becomes a useful algorithm and best design model in the optimum design. It is chosen through the iterative genetic evolution so that both the analysis and search place are essential for optimization problem. Using genetic algorithm the sensor positions with the objective function of the design variables such as MAC are defined for the optimization problem. The modal parameters of the real structure are numerically obtained using the finite element model, from which the reduced numerical modes corresponding to the sensor positions are extracted to evaluate the MAC.

2. Proposed Method:

To address the existing problems in the previous methods, MSE-AGA is presented. The main scope of this paper is to ensure safety and also to gather real time information about any damages occurred in the structures with the help of optimal sensors. This can be achieved with the help of MSE-AGA method. The main steps of the MSE-AGA method are shown in Figure 1. This method includes three strategies. First, the initial sensor locations are obtained by using MSE method. Second, the obtained sensor locations are optimized by using AGA method. Finally, by combining the both results we positioned the sensors or we optimally place the sensors in the structures.

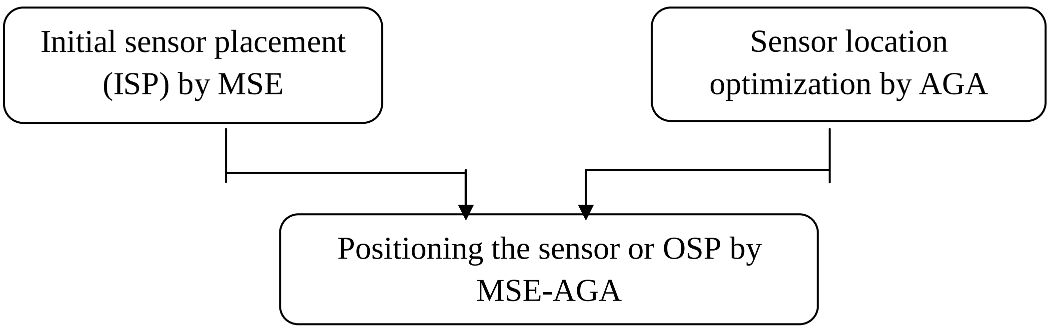

Fig. 1: Steps of the MSE-AGA method

3. Modal Strain Energy Method:

In this section, first we begin with the important structural properties needed for SHM to identify the damage. Next the proposed modal strain energy is discussed. The important structural or modal properties of SHM are Natural frequency and Mode shapes. If a model is subjected to dynamic load it oscillates to a large extent than in normal condition. This is Natural frequency. Each mechanical structure has a number of specific vibration patterns at specific frequencies. These vibration patterns are called Mode shapes [10]. Modal properties are used to estimate the response of the structure. Modal analysis can be used to find the frequency and shape of the structures at which resonance occurs, under specific constraints. The natural frequency of this Multi Degree of Freedom (MDOF) system is obtained by,

$$\det[[K] - \omega^2[M]] = \{0\} \qquad (1)$$

where K is the stiffness, ω is the frequency and M is the mass of the structures. Further, the mode shape matrix of this system is obtained by the following equation,

$$[[K] - \omega^2[M]] \{\phi\} = \{0\} \qquad (2)$$

where, ϕ is the mode shape matrix obtained from the linear coordinates of the system. Estimation of mode shapes for more than one mode is employed; they don't depend on forces or loads acting on the structure. The size of all matrices is N x N where N is the number of degree of freedom of the MDOF system. Having known mode shape matrix and stiffness matrix the MSE values is evaluated. Modal strain energy has been considered in research as a damage index because it is sensitive to damages in structures and used in assessing the extent and location of the structural damages in 2-dimmensional structures. Modal strain energy is proposed to detect multiple damages [11]. It is more effective for detecting damage and they use modal properties as a damage index. It is the form of mechanical work caused in stressed state of structures which occurred due to the environmental changes. Generally the locations that have high modal strain energy are chosen for locating sensors. The MSE is obtained from the mode shape matrix and stiffness matrix it is given by,

$$MSE = \phi^T K \phi \quad (3)$$

where, ϕ is the mode shape matrix, K is the stiffness matrix and ϕ^T is the transpose of mode shape matrix. MSE sensitivity to detect location and severity of damages limits localizing and identifying the extent of multiple damages with low accuracy and high noise. In order to detect structural damages, inverse problem solving methods have also been used. As one of the inverse problem solving methods, genetic algorithms (GA) have been widely used to detect damages as a concept of model updating. The energy contained in the measured DOFs for each mode should be a significant portion of that mode. This strain energy method helps to select those sensor positions with possible large amplitudes, and with the signal to noise ratio parameters, which is critical in harsh and noisy circumstances.

4. Adaptive Genetic Algorithm Method:

In recent years, Genetic Algorithms (GA) is gaining wide attention by the research community. GA is rapidly growing area of Artificial Intelligence. It is categorized as subclass of evolutionary algorithms [12]. It is applicable to large number of optimization techniques in science and industry. Optimization is the process of making things better [13]. Optimization can be defined as the science of determining the 'best' solutions. Optimization algorithm either minimizes or maximizes the value of the objective function depending upon certain criteria. Adaptive genetic algorithm (AGA) presented initially in searches for a global optimal solution using three main genetic operators in a sequence selection, crossover, and mutation. AGA is same as genetic algorithm which is powerful and widely applicable stochastic search technique used in computing to find true or approximate solutions to optimization and search problems based on the concepts of natural selection and natural evaluation. AGA applies the principles of survival of the fittest, selection, crossover, and mutation on the individuals to get hopefully new better individuals. The AGA is adopted in this paper to improve the searching sufficiency of placing the sensors [14]. The flow chart of genetic algorithm is given by Figure 2. GA has been proved to be a powerful tool for OSP, but it also has some faults that need to be improved. In order to improve the convergence speed and avoid premature convergence, a kind of AGA is adopted here.

4.1 Fitness function:

The fitness function is the function that the algorithm is trying to optimize by using the objective function.

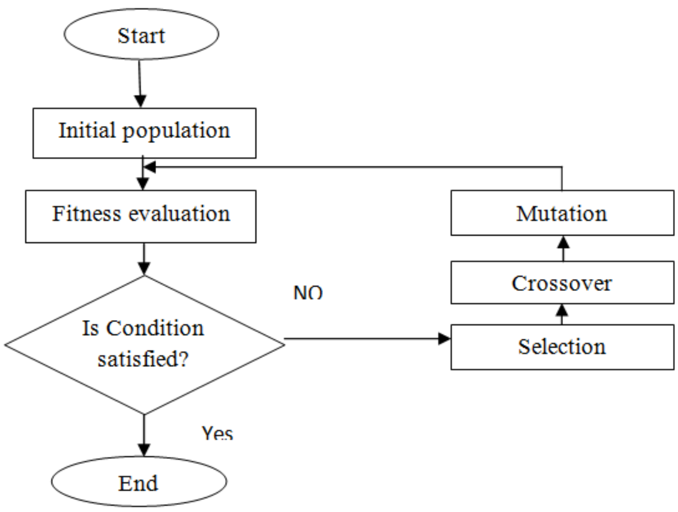

Fig. 2: Flow chart of genetic algorithm

The fitness function is obtained from the MAC matrix for this AGA process and it constructed as,

$$f = 1 - \text{RMS} \tag{4}$$

where, RMS is the root mean square of the off-diagonal elements in the MAC matrix. The Modal Assurance Criterion is defined as scalar constant which provides a useful criterion to evaluate the correlation of modal vectors. It is the tool for estimating the structural nodes are consistent with the initial nodes. MAC matrix is defined as,

$$\text{MAC} = \frac{(\phi_i^T \phi_j)^2}{(\phi_i^T \phi_i)(\phi_j^T \phi_j)} \tag{5}$$

where ϕ_i and ϕ_j are the i^{th} and j^{th} column vectors in the modal shape matrix ϕ. The minimization of the off-diagonal terms in the MAC matrix gives a good MAC index that can guarantee the orthogonality of the measured modal vectors and increase the amount of modal information obtained from the collected data [15].

4.2 Genetic Operators:

4.2.1 Selection scheme:

Selection is the process of determining the number of times a particular individual is chosen for reproduction and thus, the number of offspring that an individual will produce. Selection provides the driving force in genetic algorithms. With too much force, genetic search will terminate prematurely. While with too little force, evolutionary progress will be slower than necessary.

4.2.2 Crossover strategy:

Crossover is the GA's primary local search routine. The purpose of the crossover operator is to produce new chromosomes. It occurs after reproduction or selection. The simplest way of performing crossover is to choose randomly some crossover point and copy everything before this point from the first parent and then copy everything after the crossover point from the other parent.

4.2.3 Mutation mechanism:

Mutations are global searches. The most common form of mutation is to take a bit from a chromosome and alter (i.e., flip) it with some predetermined probability. As mutation rates are very small in natural evolution, the probability with which the mutation operator is applied is set to a very low value and is generally experimented with before this value is fixed.

5. Result Analysis

In order to demonstrate the MSE AGA method, analysis of sensor placement on a numerically simulated three storey structure is provided below. The process of OSP is done on that building by using the MSE-AGA method. This method is executed in step by step process according to the modal analysis and genetic theory. Three major steps are used to evolve or place sensor by MSE-AGA method. Initial sensor placement is the first step of the methodology which is done with the help of MSE method. Any dynamic characteristics of a structure are determined by a modal analysis. It is very important for dynamic load conditions. So to ensure the modal properties of the structure, the MSE method is used. It is an efficient method of the structures and it is calculated based on the equation (3). The plot of Modal strain energy is shown in Figure 3 which is determined by the MSE values of the building. From the Figure 3 it is observed that MSE values of all nine nodes in the chosen three storey building is plotted according to their strain energy values.

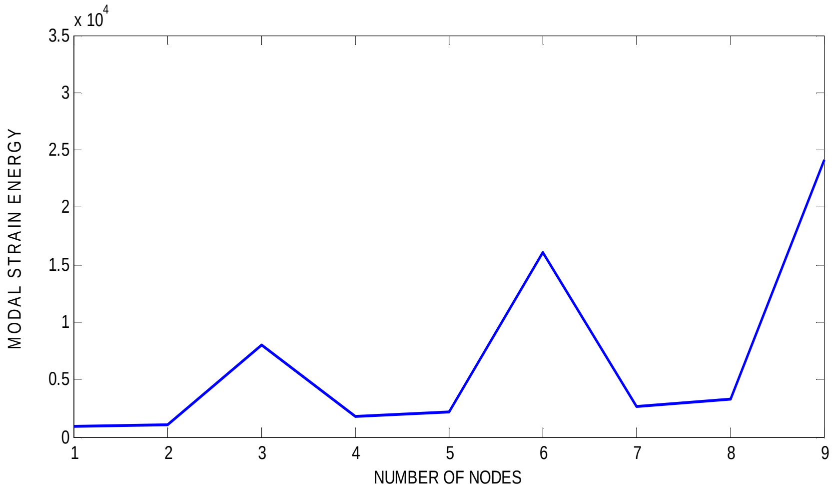

Fig. 3: Modal strain energy for sensor placement.

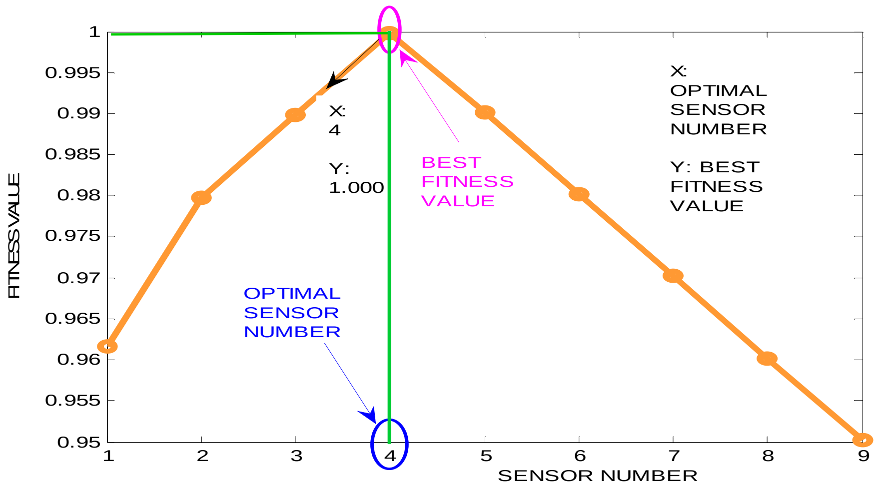

Fig. 4: Fitness function values with different sensor numbers.

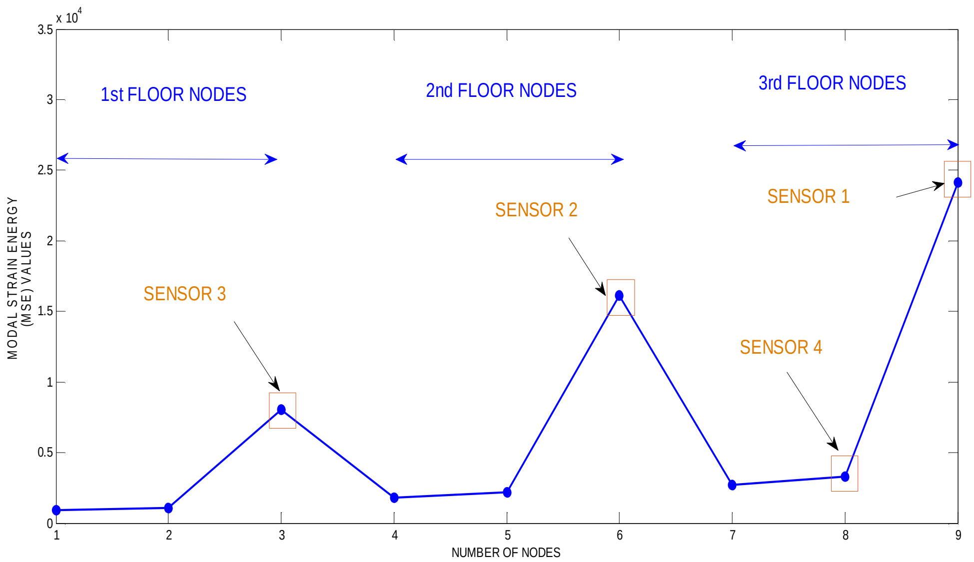

Fig. 5: Optimal result of MSE-AGA.

Sensor location optimization is the second step of methodology which is done with the help of AGA. The AGA is utilized to determine the optimal number and locations of the sensors. The AGA is composed of a fitness function, a selection technique, crossover and mutation operators. These operations form a genetic loop of algorithm as shown in Figure 2. For our optimization problem, the fitness function can be evaluated by using MAC criteria. By processing the algorithm we get the output which is shown in Figure 4. When the sensor number added to the every iteration of generations, the fitness value increased. The nine fitness values for each sensor number are obtained by processing the adaptive genetic algorithm. Among these fitness values one is to be the best fitness value according to the objective function of the problem. By processing the algorithm the fitness value reaches its maximum (The word "Maximum" represent the best fitness value) when the sensor number is set at 4 which is shown in Figure 4. If the sensor number is more than 4, the fitness value does not increase with sensor added. The reason for the contradiction is that the values determined at the newly included sensor location has a strong linear relationship with the entire previous sensor set and has high probability to place the sensor. Therefore, 4 are determined as the optimal sensor number and optimal sensor locations according to its best fitness value. These are all about sensor location optimization. Finally the output of MSE (ref. Figure 3) and the output of AGA (ref. Figure 4) are studied. By combining these two results the required optimal sensor number and sensor locations are obtained which is shown in Figure 5. From the Figure 5 it is observed that, the sensor number which has the best fitness value which is obtained from AGA is designated as "Optimal sensor number" i.e., 15 and these optimal sensors are located at points of high MSE which obtained from modal strain energy method. To get a better understanding a three storey building was taken for the study. For further research higher degree of freedom or any other structure will be taken.

Conclusion:

Optimal Sensor Placement (OSP) is achieved by using MSE-AGA method. This method utilizes the modal analysis and genetic theory to achieve optimal sensor locations. In this paper, a three storey building is taken for placing sensors optimal. First, the initial sensor placement is done by MSE method and the modal analysis is carried out, which gives mode shape matrix and it has been used for the process of MSE analysis of that building, results MSE values. Then the points of high MSE values are chosen as the locations for placing initial sensors. Second, the AGA technique is used for the optimizing the number of sensors and its locations are obtained from initial sensors which gives the best fitness value and the corresponding sensor number is said to be optimal one. Due to the adaptive crossover and mutation factors, AGA has a good searching ability and short computation time. Finally, the optimal numbers of locations are identified and sensors are placed in that building by combining these two results. The determination of optimal location of sensors is thus made easier through the introduction of MSE concept. The optimized sensor location will be extremely beneficial to gather accurate results, reducing structural costs of the systems, and to ensure safety.

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