International Journal of Enhanced Research in Science Technology & Engineering, ISSN: 2319-7463
Vol. 3 Issue 6, June-2014, pp: (7-16), Impact Factor: 1.252, Available online at: www.erpublications.com

Meta-heuristics Approaches for the Placement of Piezoelectric Actuators/Sensors on a Flexible Cantilever Plate: A Review

Neeraj Sehgal[1], Monu Malik[2], Deepak Chhabra[3]
[1,2,3]Department of Mechanical Engineering, University Institute of Engineering &Technology,
Maharshi Dayanand University, Rohtak, Haryana, INDIA

Abstract: Meta-Heuristics approaches are general algorithmic framework, often nature-inspired and designed to solve Non-Polynomial complete optimization problems in active vibration control and have been a growing research area for the past two decades. Optimal piezoelectric sensor and actuator locations on plate structures for respective objective function and modes of interest are presented. This paper discusses various meta-heuristic techniques such as evolutionary approach (genetic algorithms), simulated annealing, tabu search, swarm intelligence and other recent approaches. The importance of this paper is to incorporate various prevailing issues, open problems of meta-heuristic approaches its implementation, its usage, comparison, hybridization and its scope of future research in the aforesaid area.

Keywords: Meta-Heuristics, Optimal placement, Evolutionary approaches, Active vibration control.

Introduction

The problem of determining optimal locations of actuators/sensors for the control of large flexible structures is of considerable interest in engineering design where an improved performance and efficiency of response is sought from each controller. Most of the studies in optimization of location and sizing have been based on finite-dimensional modal analysis, and the techniques employed have concentrated on suppression of vibration of the first few modes. While these modal based techniques are attractive for the cases where exact or approximate mode shapes are readily available, they fall short in analyzing structures with more complex geometry, or in cases where control of multiple modes including higher ones are desired.

Optimal Number & Placement of Sensors/Actuators in Active vibration control (AVC)

Tzou et. al. [1] showed that symmetrically distributed piezoelectric sensor/actuator can lead to minimum or zero, sensing/control effects for anti-symmetrical modes of structures. The performance can be improved by using sensor/actuators layer into a number of collocated sub-segments. Hence the modal sensitivity and modal feedback factors can be formulated for sensor/actuator configurations. Padma et. al. [2] investigated modeling and control issues related to piezoelectric sensors and actuators. Hamilton’s principle is applied to obtain a linearized equation of motion and then Eigen value problems are solved to find out the natural modes. The passivity based controller design is proposed to deal with the issues of model idealities. Fariba et. al. [3] investigated optimization of vibration suppression of a beam cantilevered on one end to a rotating hub, in which control problem is presented as infinite dimensional LQR problem. After that, an approximation frame work based on a Legendre polynomials based Galerkin method for approximating the control system is developed.

Tarunraj et. al. [4] proposed the optimization criteria for beam based on beam modal cost and modal controllability. Optimal location and size for beam with various boundary conditions are determined for a single pair and for two pairs of piezoelectric patches. It has also been shown that the two pair actuators are more efficient then a single pair in controlling the bending vibration. Victor M.Franco Correia et. al. [5] formulated a higher order finite element model and an analytical closed form solution to study the mechanics of adaptive composite structure bonded with piezoelectric actuators and sensors. And they also proposed the optimization scheme with respect to thickness of lamination and with respect to geometry of actuator. Park Un Sik et. al. [6] introduced a balanced co-ordinate system by using new measures of modal controllability and observability for optimal placement of sensors and actuators. They have verified the effectiveness of their proposed method on a simply supported flexible beam.

Hongwei Si et. al. [7] investigated the optimization of the number of actuators via the input energy correlative matrix. They observed that optimization of size and locations of actuators have no relation with the initial conditions of structural vibration, and the gain of controller, so the optimization method is good compatibility and utility. M.R Kermani et.al.[8] studied the optimum location and the size of actuator which are based on singular value decomposition of the controllability grammian of the system. It is shown that optimum value of thickness ratio (of the beam with respect to piezoelectric actuator),can be found by maximize all singular values simultaneously. The whole performance of the dynamic system is dependent on three actuator characteristics parameters namely relative thickness, location and length of the actuator. Seba et. al. [9] used optimization techniques in the location of extromechanical actuator in a car chassis sub-frame to control the vibration. They introduced the spill-over effect resulting from the neglected higher modes in the model reduction part. By using GA optimization algorithm, we can select best three optimal positions for collocated sensor/actuator among whole 298 possible positions.

Kim et. al. [10] formulated an objective function based on cost analysis and design variables appropriate for transient vibration suppuration of a flexible structure. The spatial design variables produce a optimize distribution which convey all information about the optimal number, size and optimal location of active layer patches simultaneously. Dhuri et. al. [11] showed that favorable location for placing piezos, based on minimal natural frequency changes are iteratively evolved from an initial configuration where, the whole plate is covered with piezoes. In the event of failure of the active system, the dynamics of the structure with piezos will therefore become significant. For finding out piezo mounting location, a modal controllability approach has been used. This procedure is demonstrated by finding good piezo locations for the simply supported square, swept-back circular and rotating rectangular plate considering twisting as well as bending modes. Gupta et. al.,[12] presented that the optimal placement of sensor/actuator for AVC can be find out by optimization techniques like genetic algorithms, swarm algorithms, sensitivity analysis, simulated annealing and tabu search etc.

The criteria for optimization can be based on maximization of modal force/moment applied by the actuator; minimal change is host structural dynamics, maximization of deflection of the host structure, desired host structural dynamics, minimization of control effort, minimization of host vibration, maximization of degree of controllability/observability of modes of interest etc.

Why we are doing this paper work?

As the recent work has been done on the optimization criteria for the placement of piezoelectric sensors/actuators on a smart structure(Gupta et.al. 2010). But, the optimization techniques are not discussed so far at a broad level. So, this work explain the various optimization techniques for piezoelectric actuators and sensors on smart structures for the purpose of active vibration control and how these optimization techniques can be implemented.

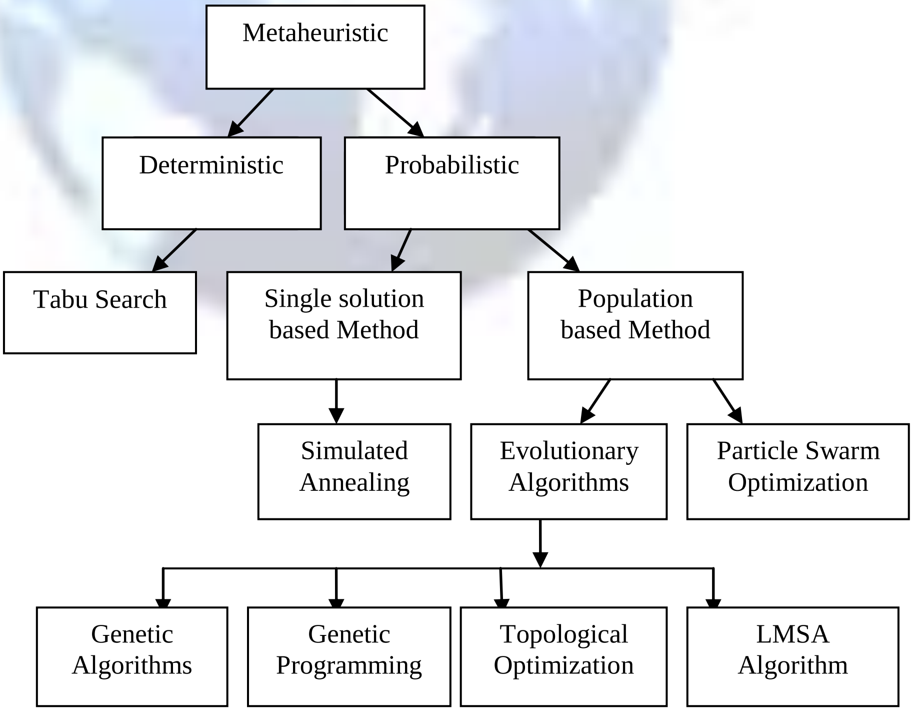

Fig : Tree of Meta-heuristics

All these techniques are useful in finding optimal locations/positions of piezoelectric actuators and sensors.

Table 1: Actuator/Sensor Optimization Summery

Sr. No.	**Source**	**Objective Function**	**Design Variables**	**Solution Method**	**Actuator/Sensor type**	**Applications**
1.	K Ramesh & Narayanan	Minimizing the control voltage & norms.	Actuator/sensor pair location	Binary coded GA(0,1 optimization)	Discrete pair	Cantilever Plate, Simply supported Plate
2.	Tarapada Roy et. al.	Max. controllability index,max. close loop damping	Dynamic oscillation & static displacement	Improved GA	1 pair of piezo actuator & sensor	FRP composite shell structures
3.	Seba et. al.	Spill-over effect	3 optimal position of A/S in 298 positions	Improved GA optimization technique	Electo-mechanical actuators	Car chassis sub-frame
4.	Panigrahi et. al.	Minimizing the variations	Length, width & depth	GA	Pair of S/A	Beams
5.	Chhabra et. al.	MCSVD	Location of actuators	GA with FEM	Piezoelectric actuators	Thin plate
6.	Yan et. al.	Minimization of vibrations	Optimal location &position	GA	2 PZT active members	Truss structure
7.	Jin et. a.	Maximization of dissipation of energy	Actuator location	Fuzzy controlled GA (MGA)	1 pair of PZT S/A	Simply supported, cylindrical shell & clamped SS plate
8.	Woo Kim et. al.	Minimizing control energy consumption	Critical coverage ratio	Topologically optimization technique	Active layer members	Any plate or beam structure
9.	Charles et. al.	Minimization of dissipated energy, max. of natural frequency	Actuator location	Multi-objective optimization technique	Discrete actuators	Any structure
10.	Tarunraj et. al.	Controlling the bending vibration and modal controllability	Boundary conditions and beam's size	Generalized optimizations techniques	Single pair and 2 pairs of PZT patches	Beams
11.	Park Un Sik et. al.	Modal controllability and observebility	Balanced co-ordinates	Hamdan and Nayfeh's measures	No. of pairs of actuators and sensors	Simply supported flexible beam (large space structures)
12.	A.M.Sadri et.al.	Max. (modal controllability or max. controllability Grammian)	Co-ordinates of center of actuator, size of actuators	GA	2 rectangular PZT actuator patches	Simply supported plate
13.	Adali et.al.	Min.(Max. deflection)	Actuator location	One dim. Optimization algorithm	One pair of PZT actuator patches	Laminated beam

14.	Qiu & Wu et. al.	Max. (controllability Grammian & degree of controllability & observebility)	Location of actuator & sensor	Energy optimal placement strategy	1 pair of PZT S/A patches	Flexible plates
15.	Dhuri et.al.	Modal controllability approach	Vary from structure to structure	Generalized approach (GA)	No. of PZT patches pairs	Simply supported square, circular, rect. Rotating plates
16.	Safizadeh et.al.	Max. observebility Grammian	Modal sensing constants and Eigen function of plate	GA + DOA	Pair of piezo sensors	Flexible plate structure
17.	Daraji et.al.	Min. of linear quadratic index, first six modes of vibrations	Actuator locations	Improved GA(half and quarter chromosomes)	Piezoelectric pairs	Cantilevered and clamped plate

Optimal placement of Actuators/sensors for AVC using Genetic Algorithms :

Genetic algorithm (GA) is a search heuristic that imitates the process of natural selection. This heuristic (also called a metaheuristic) is routinely used to generate useful solutions to optimization and search problems. Genetic algorithms are related to the larger class of evolutionary algorithms (EA), which provides solutions to optimization problems using techniques inspired by natural evolution, such as inheritance, mutation, selection, and crossover.

A.M Sadri et. al. [13] suggested two criteria for optimal placement of piezoelectric actuators by using modal controllability and the controllability grammian. Two piezoelectric actuators are optimally placed on a simply supported beam using GA. Initial chromosomes have been taken as four co-ordinates which are centers of actuators. The fitness value (Measure of controllability) is calculated for each co-ordinate set. Han et. al.,[14] showed Genetic algorithms is used to find out optimal locations of piezo sensors and actuators for a cantilevered composite plate with the consideration of observability, controllability and spillover prevention. By using GA, significant vibration reduction for the first three modes can be done. The process of GA is carried out by producing child generation with the cross over of selected to parent chromosomes. Some bits of chromosomes of child generation are changed via mutation process. Cross-over is considered as primary while mutation is a complementary operator which restricts converging to a local optimum. Arora et. al. [15] indicated that Global optimization method can be divide into two types : deterministic and stochastic. Deterministic method use the global minimum by an exhaustive search over the constrained set. Whereas stochastic methods have been developed as some variation of the pure random search. These methods can be used for both discrete and continuous problems. The stopping criteria for the stochastic methods tend to be simple in their general idea. K.M.Liew et.al. [16] designed the genetic algorithm (GA) for searching optimal actuator voltage and displacement control gains for the shape control of the functionally graded material (FGM) plates. In GA, initially population that consists of multiple individuals is randomly generated. The cross-over operator to the pairs of individuals is chosen to generate children to make next population. The shape control of the FGM plates studied under a temperature gradient by optimizing (i) the voltage distribution for the open loop control, and (ii) the displacement control gain values for closed loop feedback control. The results proved that GAs are very effective tools for shape control of the FGM plates and beams. Ryan R. Orszulik et. al. [17] implemented Genetic algorithm to identify the transfer function of an experimental system consisting of a flexible manipulator with a collocated set of piezoelectric sensor/actuator pair. Iteratively implemented GA is required to optimize all the controller parameters by the minimization of the closed-loop $H\infty$ norm. In GA process, the cross-over operator creates the new individuals by merging to individuals from current generation. Mutation operator modify part of an individual randomly. A selection operator is selected that propagate a portion of the parent generation forward as well as best of newly formed generation of children.

Chhabra et.al. [18] showed the optimal placement of piezoelectric actuator on a thin plate can also be done by the use of Modified Control Matrix and Singular Value Decomposition (MCSVD) approach. To suppress first six modes, ten piezoelectric actuators are used on a simply supported beam by using Finite Element Method. The singular value of column control matrix which is an outline of ten actuators, is considered as the fitness function.GA is used to find out optimal positions by maximization of this fitness function. K.Ramesh et. al. [19] showed a model based LQR controller is used for optimal placement of collocated piezoelectric actuator/sensor paired on flexible beam. Euler-Bernoulli beam theory based FEM method is used in this. LQR performance is taken as objective for finding optimal location where as the problem is formulated as a multi input- multi output (MIMO) modal control. Genetic algorithm is used in the framework of a zero-one optimization problem for solving sensor/actuator location problem. Optimal location of collocated actuator-sensor pair is carried out for the different boundary conditions of beams like cantilever clamped and simply supported.

Optimal Placement of A/S in AVC By Using Improved GA :

When GA is used with some improvement on the basis of their coding-encoding such as Float-encoded, Binary-encoded and integer coded etc.,then it is called Improved GA. Also the improvement can be done by using advance techniques of optimization and control.

Float-encoded GA :

Hongwei et. al.,[20] indicated that Genetic algorithms are highly parallel, adaptive and guided random search techniques. Float- encoded genetic algorithms is very effective generic optimization tool in which each design parameter is represented a Floating point decimal number with 15 digits. So the floats encoding method has advantages over standard GA in that it avoids the difficult encoding and decoding of binary data that is required in traditional GA.

Binary-encoded GA :

Narayanan et. al.,[21] presented that GA is used to solve the 0,1 optimization problem for finding out the optimal location of sensor-actuators problem. A better combination of GA with finite element method is used for analysis of a cantilever plate in active vibration control. Dejun et.al.[22] introduced a binary coded GA based combined optimal placement and LQR control scheme which addresses the controllability aspects in the wireless vibration control of plate structures by using photo structive actuators. The GA- LQR combination maximizes modal force index, the closed loop damping and maximizes input light intensity of the actuator. This study indicated that the use of an array appropriately positioned actuator can provide good controllability of the whole structure.

Integer-coded GA :

Tarapada Roy et. al. [23] introduced an integer coded GA based open loop procedure for the optimal placement of actuator for maximizing controllability index. With this, a real coded genetic algorithm (RCGA) based linear quadratic regulator (LQR) control scheme has been developed and implemented .In this process the uniform cross-over is introduced in which a random mask is generated that determine which bits are copied from one parent and which from the other parameter. A new mutation process in which a one digit positive integer value is generated randomly which replaces the old one when mutating. Vashist et. al. [24] showed that an integer coded GA based on controllability index is used for the optimal placement of piezoelectric actuator on a thin plate. This index measures the input energy required for controlling structure by using PZT actuators. The LQR scheme is applied to study control effectiveness.

Improved GA :

Roy et. al.,[25] presented an improved GA based LQR can be brought into use to control the dynamic oscillation due to mechanical loading, and the static displacement due to the thermal gradient, of the fiber reinforced polymer composite shell structure. In this a real coded GA along with simulated binary cross-over(SBX) at parameter based mutation operators has been used.This can be done by maximizing the close loop damping ratio within the limit of input actuator voltage for active vibration control. Roy et.al. [26] presented the optimal vibration control for smart Fiber Reinforced Polymer (FRP) composite shell structure can be improved by GA based combined optimal location of collocated piezoelectric actuators/sensors considering the control spill-over and LQR based control scheme. By doing this, we can minimize the control spill- over of higher order modes and get superior performance in terms of settling time with large reduction of control effort (Actuation Voltage) and closed loop damping ratio. Daraji .al.[27] presented the search space for optimizing the location of ten actuators gives $1.73\text{x}10^{13}$ solutions, that is known as global optimum. So, a new quarter and half chromosomes technique based on symmetry is introduced, which reduces the number of location to only 8 or 10 on a 500x500 mm square plate, reducing the search space locations up to 99.99 %. FEM and Hamilton’s principle based on first order shear deformation theory is used to investigate the isotropic plates bonded piezo locations. A cantilever and clamped plate is experimented for the placement and feedback gain optimization of 8 and 10 sensor/actuator pair to attenuate the first 6 modes of vibration, by using minimization of linear quadratic index as an objective function.

Panigrahi et. al. [28] presented that regarding the application of Genetic algorithm, the damage in uniform strength beam with first case on variations of depth along its length and second case on both width and depth varying can be simultaneously located and qualified. . GA with steady-state selection for reproduction purpose have been employed for which the optimization function has been formulated in term of modified residual force vectors. In this way genetic algorithm show excellent agreement with the appropriate values of parameters related to physical properties and state of damaged structures. Y J Yan et.al. [29] used genetic algorithms to search optimal locations of actuator in a space truss with multiple piezoelectric ceramic stack actuators. The disturbance acting on a structure is the key factor in the determination of optimal number and the locations of the actuators in the active structural vibration control. By using genetic algorithms, a global and efficient optimization solution of multiple actuator location can be obtained. B.Xu et. al. [30] presented structural sizing variable, actuator/sensor placement and control parameters are taken as the independent design variables in the finite element modeling of truss structure with piezoelectric members. Genetic algorithms with coding, the calculation of fitness and optimization procedure are argued to solve the integrated optimization with two types of design variables space : discrete and continuous.

Rajadas et. al.,[31] introduced the Kreisselmeier- Steinhauser(K-S) function approach, can be applied by modifying weight factor in a variety of multi- objective optimization problems. The weight factors allow a designer to take advantage of original K-S formulations characteristics, while retaining the ability to selected area of design. Marano et. al. [32] showed the multi-objective optimization can be taken out by means of a stochastic approach for the random vibrations on the basis of design variables like, the device frequency and the damping ratio. In this non-dominated sorting genetic algorithm of second version (NSGA-II) is developed to obtain the Pareto Sets and its corresponding optimization characteristics. Seely et. al. [33] showed that it is very important to locate the discrete actuators optimally on a structure in order to achieve the most efficient implementation of their special properties. A multi-objective optimization technique is used to formulate the combined problem which includes the discrete actuator location and continuous optimization and structure interaction. The optimizer used in this study consists of a non-linear programming procedure for constrained function minimization based on the method of feasible directions. This optimization procedure includes actuator's location, vibration reduction, power consumption, minimization of dissipated energy and maximization of natural frequency.

Young Jin Cha et. al.,[34] presented that, by using Multi Objective Genetic Algorithm (MOGA) not only the location of sensors and actuators are optimized, but also dynamic response of structures are minimized. It shows the effect through the integration of implicit redundant representation genetic algorithms with a strength Pareto evolutionary algorithm. Alam et. al. [35] showed Multi-Objective Genetic Algorithm (MOGA) optimization technique can be used to determine a set of solutions for the amplitudes and time locations of impulses for a multi model command shaper. This is very effective method for both the time domain as well as for the frequency domain. With the help of this technique, rise time, reduced overshoot, settling time and end point vibration are found to be conflicted to each-other due to construction and mode of operation of a flexible manipulator. This multi-objective optimization is applicable in the designing of command shapers for controlling the vibrations. Chhabra et. al. [36] proposed that the optimal number and locations of collocated/non-collocated actuators and sensors can be find out by using hybrid Multi-Objective Genetic Algorithm-Artificial Neural Network (GA-ANN). LQR control gain can also be find out at the same time. Trade-off objective function ensuring good observability/ controllability, minimizes the spill-over effect and maximizes closed-loop average damping ratio are formulated for multi objective optimization problems.

Optimal Placement of A/S in AVC by Using Hybrid Genetic Algorithms:

When genetic algorithm is used with other kind of optimization technique simultaneously for the same problem, then this combination is known as Hybrid Genetic Algorithms. Some are as follow:

Chhabra et. al. [37] presented that the appropriate location of eight actuators on cantilever plate can be find out by Modified Control Matrix and Singular Value Decomposition (MCSVD) approach using Modified Heuristic Genetic Algorithm (MHGA). MHGA is an integer coded technique used to improve searching effectiveness for finding optimal location. A LQR control scheme is used. This combination gives greater closed loop damping ratio and lesser computation requirements. Wei Liu et. al. [38] developed a spatial $H\infty$ norms based scheme for finding the optimal locations of actuators and sensors in controlled flexible structures. To solve resulting non-linear optimization problem, genetic algorithm is used for controlling the vibration on a plate structure effectively. In this, the problems of optimization variables are the SA locations which are either spatial co-ordinates or the index number. The chromosome is chosen to be binary encoded string for the node index. Thus, the GA with SA problem makes it a hybrid technique. Dhingra et. al.,[39] presented a synergistic blend of genetic algorithms and gradient based search techniques is used for the solution of optimization. This technique not only gives the solution for optimal positioning of collocated actuator/sensor, but also designs optimization problems with discrete and continuous variables with similar efficiency. Safizadeh et.al. [40] found the best position of piezoelectric actuator for vibration control can be done by Genetic Algorithm and developed optimization algorithm (DOA), which is based on controllability grammian. The comparison between the two mentioned techniques is also done, and the results showed that DOA is far better than conventional GA. In order to achieve the optimization goal, the square plate with all clamped edges is segmented into 99x99 equal segments with 10000 nodes. The objective function is evaluated for all nodes and then DOA is used to find out the maximum value of performance index and its position as a best location of actuator. M.R Safizadeh et. al. [41] indicated that,to optimize the location of sensor, the observability grammian is acquired using the natural frequencies, modal sensing constants and Eigen function of plate. The observability performance index is optimized by Developed Optimization Algorithm and genetic algorithm(which becomes a hybrid optimization technique). First two modes of frequency are much more observable than initial sensor location in the effectiveness of proposed location.

Optimal Placement of A/S in AVC Using Simulated Annealing Algorithms:

Simulated annealing (SA) is a generic probabilistic metaheuristic for the global optimization problem of locating a good approximation to the global optimum of a given function in a large search space. The name and inspiration come from annealing in metallurgy, a technique involving heating and controlled cooling of a material to increase the size of its crystals and reduce their defects. Both are attributes of the material that depend on its thermodynamic free energy. While the same amount of cooling brings the same amount of decrease in temperature it will bring a bigger or smaller decrease in the thermodynamic free energy depending on the rate that it occurs, with a slower rate producing a bigger decrease. This observation of slow cooling is implemented in the Simulated Annealing algorithm as a slow decrease in the probability of accepting worse solutions as it explores the solution space. Accepting worse solutions is a fundamental property of metaheuristics because it allows for a more extensive search for the optimal solution.

Aditi et. al.,[42] presented that Simulated annealing algorithms is effective in actuator locations, composites and circuit board design. A multi-objective optimization can be done by including both discrete and continuous design variables using simulated annealing algorithm. After the initialization of design variables, functional and sensitivity analysis are done. Then simulated annealing technique with the Kreisselmeier-Steinhauser multi-objective optimization approach which formulate the multi-objective optimization problem.

Yang et. al. [43] showed that, to optimize the placement of the active members in an adaptive truss structure, the dissipating control energy method has been employed to suppress vibration. This method is treated consistently through the use of dissipating control energy over infinite time interval within the frame work of the simulated annealing algorithms. It is possible to catch the exact global optimum solution; all thought it require a high computational cost. Jose M.Simoes Moita et. al. [44] indicated that, to minimize the vibration amplitude and to maximize the first natural frequency, the simulated annealing algorithm is used. A feedback control algorithm is used to achieve a mechanism of active control of the structure dynamic response. Also the SA method is employed to optimize the piezoelectric patches position in order to maximize the control capacity of a defined set of actuator in a simply supported laminated plate.

Optimal Placement of A/S in AVC Using Tabu Search Algorithms:

Tabu search is similar to simulated annealing in that both pass through the solution space by testing mutations of an individual solution. While simulated annealing provide only one mutated result, tabu search provides many mutated results and moves to the result with the lowest energy of those provided. In order to prevent cycling and enhance greater movement through the solution space, a tabu list is maintained of partial or complete solutions. It is forbidden to move to a solution that contains elements of the tabu list, which is updated as the results pass through the solution space.

Kincaid et. al. [45] presented a Reactive Tabu Search optimization technique for active acoustic/vibration control in structures. The procedure is described as a neighborhood structure for the 800x800 grid version of Levy No. 3. Given an interior point ($x; y$) of the grid the neighbors of this point are all of the compass points—North, Northeast, East, Southeast, South, Southwest, West, and Northwest— generated by adding or subtracting the grid size (0.025) from ($x; y$). For example, the grid point ($x; y$ C0:025) is the North neighbor of ($x; y$). At each iteration of tabu search the eight neighbors of the current point are evaluated and the best neighbor among the non-tabu and tabu neighbors, who satisfy the aspiration criteria, is selected (where best means lowest f .$x; y$/ value). The aspiration criteria checks to see if the function value at a tabu neighbor is better than the best experimental function value. If so, the tabu neighbor is said to satisfy the aspiration criteria. Once a best neighbor is selected it becomes the new current point and the ($x; y$) coordinates of the best neighbor are placed on the tabu list.

Using Swarm Intelligence:

Swarm intelligence is a computational method for multi-parameter optimization which is based on population-based approach. A population (swarm) of particles moves in the search space, and the movement of the particles is projected both by their swarm's global best known position and own best known position. Similar to GA, the Swarm intelligence method depends on information sharing among population parameters. In some cases the Swarm intelligence is often more computationally efficient than the GAs, especially in unconstrained problems with continuous variables.

Dutta et. al.,[46] presented that, in Swarm intelligence, optimal locations of sensors-actuators and feedback gain are obtained by maximizing the energy dissipated by the feedback control system. In Artificial Bee Colony (ABC) algorithm the possible solution to the optimization problem is represented as the position of a food source. After initialization, the population of positions is directed to repeated iteration of the search process of the employed bees, onlooker bees and scout bees. Glowworm Swarm Optimization (GSO) algorithms mimics the phenomenon in which the glowworm produces natural light which is used as a signal to attract a mate or to attract prey. Each glowworm carries a quantity of luminescence called luciferin. Swarm intelligence approaches mimic the behavior of insect swarms. Marinaki et.al.,[47]showed Multi-objective particle swarm optimization(MOPSO) using a different velocity equation, based on the solution of each objective function, is used to optimize the locations of PZT actuators and sensors. Also the parameters of

Fuzzy control system can be optimized which are used for the vibration control in smart structures. Kennedy et. al. [48] presented Particle swarm optimization is computationally inexpensive in terms of both speed and memory requirements. PSO requires only primitive mathematical operators. PSO also performs well on GA functions to optimize the locations of PZT sensors and actuators. It is of the biologically derived algorithm form which occupies the space in nature between evolutionary search, which requires eons, and neural processing, which occurs on the order of milliseconds. Also, it lies between GA and evolutionary programming. Zhan et. al. [49] presented Adaptive particle swarm optimization (APSO) is also a type of PSO, which is better in search efficiency then classical PSO.
It uses a real time evolutionary state estimation procedure for the optimization of PZT actuators and sensors that includes exploration, exploitation, convergence and jumping out in each generation. Also, APSO controls acceleration co-efficient, inertia weight, and other algorithmic parameters at run time automatically, thus APSO substantially improve the performance of PSO paradigm.

Using Topological optimization:

Topological optimization is a mathematical approach that optimizes position and location of PZT actuator/sensors within a given parametric space, for a given set of loads and boundary conditions such that the resulting optimal solution meets a prescribed set of performance targets. Topological optimization has been implemented through the use of finite element methods for the analysis, and optimization techniques based on the asymptotes, genetic, optimality criteria method, level sets, and topological derivatives.
Zhoa et. al.[50] showed the topological optimization method which is a continuous variable optimization method is used for piezoelectric truss structures vibration control by using optimal placement of active bars. In this method 0-1 discrete variable is defined to solve the location of piezoelectric active bars. A new sensitivity analysis method is introduced for the vibration control of piezoelectric truss structure with the time integration of structural transient dynamic response. For solving the optimization problems a two phase procedure and the sequential linear programming algorithm is proposed. Kim et. al. [51] presented that for the suppression of transient vibration in a flexible structure, a new optimization framework for distribution of a active damping layer is formulated. This process consumes minimum control energy for the system performance. To apply optimization algorithm, a sensitivity analysis for the input and the output cost function is needed. A topologically optimized distribution is taken, which can give all information about the size optimal number and optimal location of active layer patches at the same time.

Using Other Optimization method: Some other optimization techniques can also be implemented for the optimization problems for actuator/sensor location in active vibration control,which are as follows:

Gradient based method: Murat Gueny et. al. [52] developed a closed loop optimal location selection method for sensors and actuators in flexible smart structures, in which its location optimization is done with gradient based unconstraint minimization method and H∞ controller. As the iterative gradient search algorithm is used, the partial derivatives of the approximate algebraic Riccati equation with respect to the design parameters are taken.

LMSA Algorithm: Hu Hongsheng et. al. [53] showed that in a flexible cantilevered beam bonded with self- sensing piezoelectric actuators, the least mean square (LMS) adaptive algorithm is applied into the dynamic balance signal separation between piezoelectric self sensing actuator and excitation signals. The algorithms ratiocinative process and convergence performance is further analyzed. Smart structure active vibration control by LMS adaptive algorithm is simulated by the software by picking up sensing signal. Zh-Cheng Qiu et.al. [54] indicated that, in flexible spacecraft cantilever plate structure, such as Sun plate and Satellite antenna, the vibration problem will be caused by the parameter uncertainties and environmental disturbances. To suppress these vibrations of smart flexible clamped plate, the piezoelectric ceramic patches are used as sensors and actuators. Firstly, modal equations and piezoelectric control equations of cantilever plate are derived. Secondly, an optimal placement method or technique to locate piezoelectric actuator and sensor is developed which is based on degree of observability and controllability indices for cantilever plate. Thirdly, after it an efficient control method by combining positive position feedback and proportional- derivative control is proposed to reduce the vibrations.
Qiu & Wu et. al. [55] proposed an energy optimal placement strategy for PZT actuators/sensors placement in active vibration control of flexible plate. For this strategy the optimal placement indices of sensors and actuators location are adopted by means of controllability grammain matrix, this is based on degree of observability and controllability of the dynamical model including bending and torsion modes, the input matrix was properly weighted according to the contribution to observability and controllability for corresponding modes.

Conclusion

Various optimization techniques have been studied for the optimal placement of piezoelectric sensors/actuators on a smart structure for the purpose of active vibration control. And also how these optimization techniques can be implemented is studied. In this paper we discussed various meta-heuristic approaches such as evolutionary approach (genetic algorithms), simulated annealing, tabu search, swarm intelligence and other recent approaches. Also the comparison, hybridization and future scopes in aforesaid area for these approaches are discussed.

References

[1]. Tzou H.S and Fu H.Q., 1994. "A Study of Segmention of Distributed Piezoelectric Sensors and Actuators," Journal of Sound and Vibration., Vol. 172(2), pp :247-259.

[2]. Padma Akella., Xin Chen., Welying Cheng and John T.Wen., 1994. "Modeling and Control of Smart Structures with Bonded Piezoelectric Sensors and Actuators," Smart Mater. Struct., Vol. 3, pp :344-353.

[3]. Fariba Fahroo and Wang., 1997. "Optimal Location of Piezo-Ceramic Actuators for Vibration Suppression of a Flexible Structure," IEEE, pp :1966-1971.

[4]. Tarunraj Singh and Robert C.Wetherhold., 1997. "Realistic determination of the Optimal Size and Location of Piezoelectric Actuator/Sensor," pp :435-440.

[5]. Victor M.Franco Correia., 2000. " Modeling and Design of Adaptive Composite Structures," Compute. Methods Appl. Mech.Engrg ., Vol.185, pp :325-346.

[6]. Park Un Sik., 2003. "Optimal placement of Sensors and Actuator using Measures and Modal Controllability and Observebility in a Balanced Co-ordinate," KSME International Journal., Vol. 17, pp :11-22.

[7]. Hongwei Si., Dongxu Li and Zhizhen Liu., 2003. " Optimization of the Number and Locations of the Actuators in Smart Structures," IEEE International Conference on Robotics., pp :841-846.

[8]. M.R.Kermani., M.Moallem and R.V.Patel., 2004. "Parameter Selection and Control Design for Vibration Suppression using Piezo-Electric Transducers," Control Engineering Practice., Vol. 12, pp :1005-1015.

[9]. Seba,Bouzid., Nikola Nedelizkovic and Boris Lohmann., 2004. "Actuator/Sensor Placement Optimization for Vibration Control Based on Finite Element Model of the Car Chassis," J.Acoust,SOC. Am., Vol. 115, pp :2575-2580.

[10]. Kim & Kim., 2005. "Optimal Distribution of an Active Layer for Transient Vibration Control of a Flexible Plate," Smart Mater. Struct., Vol. 14, pp :404-409.

[11]. Dhuri,. K D.,Seshu, P., 2007. "Favorable Locations for Piezo Actuators in Plates with Good Control Effectiveness and Minimal Change in System Dynamics," Smart Mater. Struct., Vol. 16, pp :2526-2542.

[12]. Gupta., Sharma and Thakur., 2010. "Optimization Criteria for Optimal Placement of Piezo-Electric Sensors and Actuators on a Smart Structure: A Technical Review," Journal of Intelligent Material Systems and Structures., Vol. 21, pp :1227-1293.

[13]. Sadri., J R Wright and R J Wynne., 1999. "Modeling and Optimal Placement of Piezoelectric Actuators in Isotropic Plates using Genetic Algorithms," Smart Mater. Struct., Vol. 8, pp :490-498.

[14]. Han and Lee., 1999. "Optimal Placement of Piezo-Electric Sensors and Actuators for Vibration Control of a Composite Plate using Genetic Algorithms," Smart Mater. Struct. ., Vol. 8, pp :257-267.

[15]. Arora,J.S.,Elwakai,O.A. and Chahande,A.I., 1995. "Global optimization methods for Engineering Application," Structural Optimization., Vol. 9, pp :137-159.

[16]. K.M Liew., X.Q. He and S.A Meguid., 2004. "Optimal Shape Control of functionally Graded Smart Plates using Genetic Algorithms," Computational Mechanics., Vol. 33, pp :245-253.

[17]. Ryan R.Orszulik and Jinjun Shan., 2012. "Experimental Study an Active Vibration Control using Genetic Algorithm Based System Identification and Optimized Positive Position Feedback," Smart Mater. Struct., Vol. 21, pp :1-8.

[18]. Chhabra Deepak.,Bushan Gian and Chandna Pankaj., 2013. "Optimal Placement of Piezoelectric Actuators on Plate Structures for Active Vibration Control using Modified Control Matrix and Singular Value Decomposition Approach," Internatonal Journal of Mechanical, Industrial Science and Engineering., Vol. 7, pp :90-95.

[19]. K.Ramesh Kumar and S. Narayanan., 2008. "Active Vibration Control of Beams with Optimal Placement of Piezo-Electric Sensor/Actuator Pairs," Smart Mater. Struct., Vol. 17, pp :55-63.

[20]. Hongwei and Andrew., 2000. "A Float-Encoded Genetic Algorithm Technique for Integrated Optimization of Piezo-Electric Actuator and Sensor Placement and Feedback Gains," Smart Mater. Struct. ., Vol. 9, pp :552-557.

[21]. Narayanan.S and Ramesh Kumar., 2007. "The Optimal Location of Piezo-Electric Actuators and Sensors for Vibration Control of Plates," Smart Mater. Struct., Vol. 16, pp :2680-2691.

[22]. Dejun., Shijie., 2012. "Genetic Algorithm Based LQR Vibration Wireless Control of Laminated Plate using Photostructive Actuators," Earthq Eng. & Eng. Vib., Vol. 11, pp :83-90.

[23]. Tarapada Roy and Debabrata Chakraborty., 2009. "Optimal Vibration Control of Smart Fiber Reinforced Composite Shell Structures using Improved Genetic Algorithm," Journal of Sound and Vibration., Vol. 319, pp :15-40.

[24]. Vashist K Suresh and Chhabra Deepak., 2014. "Optimal Placement of Piezoelectric Actuators on Plate Structures for Active Vibration Control using Genetic Algorithm,"SPIE 9057, Active and Passive Smart Structures and Integrated System, 905720.

[25]. Roy,Tarapada and Debabrata Chakarborty., 2009. "Genetic Algorithm Based Optimal Control of Smart Compote Shell Structures Under Mechanical Loading and Thermal Gradient," Smart Mater. Struct., Vol. 19,(115006) pp :1-12.

[26]. Roy and Chakraborty., 2009. "Genetic Algorithm Based Optimal Design for Vibration Control of Composite Shell Structures using Piezoelectric Sensors and Actuators," Int. J Mech. Mater Des., Vol.5, pp :45-60.

[27]. Daraji,A.H., Hale,J M., 2012. "Active Vibration Reduction of a Flexible Structure Bonded with Optimized Piezo-Electric Pairs Using Half and Quarter Chromosomes in Genetic Algorithms," Journal of Physics: Conference Series., Vol. 382, pp :1-6.

[28]. Panigrahi and Meccanica., 2009. “Vibration Based Damage Detection in a Uniform Strength Beam using Genetic Algorithm,” Vol. 44, pp:697-710.

[29]. Yan Y.J. and Yam L.H., 2002. “Optimal Design of Number and Location of Actuators in Active Vibration Control of a Space Truss,” Smart Mater.Struct ., Vol. 11, pp :496-503.

[30]. B.Xu., Jiang,J.S.,2004. “ Integrated Optimization of Structure and Control for Piezoelectric Intelligent Trusses with uncertain Placement of Actuators and Sensors,” Computational Mechanics., Vol. 33, pp :406-412.

[31]. Rajadas,John N., Ralph A. Jury iv and Aditi Chattopadhyay., 2000. “Enhanced Multi-Objective Optimization Techniques for Multi disciplinary Design,” Eng. Opt., Vol. 33, pp :113-133.

[32]. Marano and Quaranta., 2009. “Multi-Objective Optimization by Genetic Algorithm of Structural Systems Subject to Random Vibrations,” Greco Struct. Multidisic Optim. ., Vol. 39, pp :385-399.

[33]. Seely,Charles E and Aditi Chattopadhyay., 1993. “The Development of an Optimization Procedure for the Design of Intelligent Structure,” Smart Mater. Struct., Vol. 2, pp :135-146.

[34]. Yan Shaoze, Zheng Kai, Zhao Qiang and Zhang Lin., 2005. “Optimal Placement of Active Members for Truss Structure using Genetic Algorithm,” ICIC part- II, LNCS 3645., pp :386-395.

[35]. Alam and Tokhi, 2008. “Designin Feed Forward Command Shapers with Multi-Objective Genetic Optimization for Vibration Control of a Single Link Flexible Manipulator,” Engineering Applications of Artificial Intelligence, Vol. 21, pp :229-246.

[36]. Chhabra Deepak.,Bushan Gian and Chandna Pankaj., 2014. “Multilevel Optimization for the Placement of Piezo-Actuators on Plate Structures for Active Vibration Control using Modified Heuristic Genetic Algorithm,” SPIE 9059,Industrial and Commercial Applications of Smart Structures Technologies,90590J

[37]. Chhabra Deepak.,Bushan Gian and Chandna Pankaj., 2014. “Optimization of Collocated/Non-Collocated Sensors and Actuators along with Feedback Gain using Hybrid Multi-objective Genetic Algorithm- Artificial Neural Network,” Hindawi Publishing Corporation, Chinese Jouranl of Engineering, Vol.2014, pp: 1-12.

[38]. Wei Lui, Zhikun Hou and Michael A.Demetriou., 2006. “A computational Scheme for the Optimal Sensor/Actuator Placement of Flexible Structure using Spatial H_2 Measures,” Mechanical System and Signal Processing., Vol. 20, pp :881-895.

[39]. Dingra,A K., Lee, B H., 1994. “Optimal Placement of Actuators in Actively Controlled Structures,” Eng. Opt. ., Vol. 23, pp :99-118.

[40]. Safizadeh,M R., I.Z Mat Darus and M.Maliah., “Optimal Placement of Piezoelectric Actuator for Active Vibration Control of Flexible Plate,” Conference.

[41]. M.R.Safizadeh and Intan Z Mat darus., 2010. “Optimal Location of Sensor for Active Vibration Control of Flexible Square Plate,” IEEE., Vol. 10, pp :393-397.

[42]. Aditi chattopadhyay and Charies E Seeley,1994. “A Simulated Annealing Technique for Multi-objective Optimization of Intelligent Structures,” Smart Mater. Struct., Vol. 3, pp :98-106.

[43]. Yang F., 2005. “Optimal Placement of Active Bars in Smart Structure,” IEEE., Vol. 5, pp :1-6.

[44]. Jose M.Simoes Moita., 2006. “Optimal Design in Vibration Control of Adaptive Structure using a Simulating Annealing Algorithm,” Composite Structure., Vol. 75, pp :79-87.

[45]. Kincaid Rex K. and Keith E. Laba., 1998. “Reactive Tabu Search and Sensor Selection in ActiveStructural Acoustic Control Problems,” Journal of Heuristics, Vol. 4,pp :199–220.

[46]. Dutta,Rajdeep., Ganguli and Mani., 2011. “Swarm Intelligence Algorithms for Integrated Optimization of Piezo-Electric Actuator and Sensor Placement and Feedback Gains,” Smart Mater. Struct., Vol. 20,(105018) pp :1-14.

[47]. Marinaki.,yauwis and Georgioso., 2011. “Fuzzy Control Optimized by a Multi-Objective Particle Swarm Optimization Algorithm for Vibration Suppression of Smart Structures,” Smart Multidisc Optim., Vol. 43, pp :29-42.

[48]. Kennedy James and Russell Eberhart., 1995. “Particle Swarm Optimization,” Proceedings of IEEE International Conference on Neural Network iv., pp :1942-1948.

[49]. Zhan, Z.H, Zhang, J.Li and Y Chung., 2009. “Adaptive Particle Swarm Optimization,” IEEE Transactions on System, Man and Cybernetics ., Vol. 39, pp :1362-1381.

[50]. Zhao and Yuan Xian Gu., 2008. “Optimal Placement of Piezoelectric Active Bars in Vibration Control by Topological Optimization,” Acta Mech. Sin., Vol. 24, pp :699-708.

[51]. Kim.,Cha,Young-Jin., Anil,K.Agra., Raich.,2012. “Multi-Objective Genetic Algorithms for Cost- Effective Distributions of Actuators and Sensors in Large Structures,” Expert Systems with Application ., Vol. 39, p :7822-7833

[52]. Murat Gueny and Esref Eskinat., 2008. “Optimal Actuator and Sensor Placement in flexible Structures using Closedloop Criteria,” Journal of Sound and Vibration., Vol. 312, pp :210-233.

[53]. Hu Hongsheng and Qian Suxiang., 2007. “Self-Sensing Piezoelectric Actuator for Active Vibration Control Based on Adaptive Filter,” IEEE., Vol. 7, pp :2564-2569.

[54]. Zh – Cheng Qiu., 2007. “Optimal Placement and Active Vibration Control for Piezoelectric Smart Flexible Cantilever Plate,” Journal of Sound and Vibration., Vol. 301, pp :521-543.

[55]. Qiu Zhicheng and Wu hongxin., 2006. “Study on Optimal Placement for Piezoelectric Smart Flexible Cantilever Plate,” IEEE., Vol. 6, pp :1496-1500.