Review and Discussion of Multi-objective Optimization of Actuators/Sensors Using Artificial Intelligence Algorithms

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1. Introduction

From all of the above, we can find that multi-objective optimization of actuators/sensors has been researched in the field of structure vibration and shape control systems. However, a comprehensive comparison between different artificial intelligent optimization methods for actuator placement, number, and orientation has not been performed.

2. Body of abstract

This paper gives a review and discussion on multi-objective optimization of actuators/sensors using artificial intelligence algorithms. First, the placement and orientation optimum problems are defined. Second, the finite element analysis results for a plate are taken as an example. Third, a definition of artificial intelligence optimization algorithms are presented. Fourth, the procedures of artificial intelligence optimization algorithms are presented. Fifth, optimization results on the orientations and locations of actuators/sensors are presented, and finally, optimization results are discussed.

3. PROBLEM DEFINITION

The placement and orientation optimization problems (OOL) are a set of combinatorial optimization problems, which are complex and difficult to solve. This type of problem involves finding the route direction for n piezoelectric actuators to place in n locations. Each location is placed exactly once, and the inter-location deformation degrees are symmetric and known. The constituents of the placement and orientation optimization problem (OOL) are the following: n is the number of locations indexed by i and j; cij is the value of the deformation between location i and j; and xij are the decision variables. The value of xij equals “1” when arc (i,j) is included in the tour, and it equals “0” otherwise.

Now, the OOL can be represented as follows:

$$\text{Minimize} \quad \sum_{i=1}^{n}\sum_{j=1}^{n} c_{ij}x_{ij} \tag{1}$$

$$\text{Subject to} \quad \sum_{j=1}^{n} x_{ij} = 1, \quad i = 1,\cdots,n. \tag{2}$$

$$\sum_{j=1}^{n} x_{ij} = 1, \quad j = 1,\cdots,n \tag{3}$$

$$(x_{ij}) \in X \quad x_{ij} = 0 \ or \ 1, \forall i, j = 1,\cdots,n$$

Obviously, with n (n≤49) piezoelectric actuators, determine from a total of m (in this paper, m=49) the optimal placements and corresponding d (in this paper d=392(49×8)) optimal orientations for each actuator to obtain the best route program for the vibration response deformation of a thin plate. There are two types of optimization problems: For the first problem, multiple actuator locations and corresponding orientations can be obtained for a certain vibration response deformation. For the second problem, only one set of actuator locations and corresponding orientations are the most effective for a certain type of vibration response deformation.

Note that the two problems are related to finding a set of optimal locations and orientations for n piezoelectric actuators, from a maximum possible 49 candidate locations and 392(49×8) candidate orientations, with more than C_{392}^{n} possible solutions, which will yield the best correction to the surface distortions of a plate. The actuator candidate locations are most likely the same for different types of vibration response deformations, but the corresponding orientations are usually not the same. The second problem is a multiple and more challenging problem. These are very large, complex and computationally intensive combinatorial optimization problems. The number of different candidate sets is

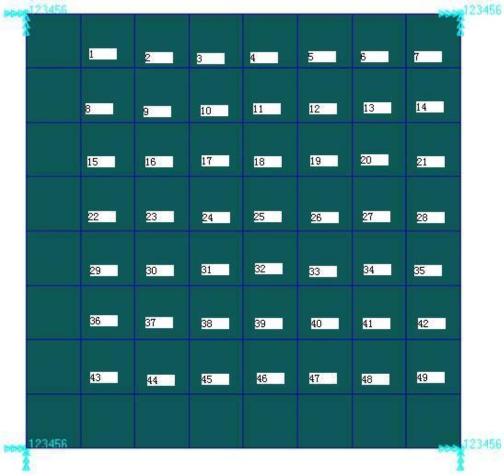
$$C_{392}^{n} = \binom{n}{392} = \frac{392!}{n!(392-n)!} \quad (n\leq 49) \tag{4}$$

4. FINITE ELEMENT MODELING

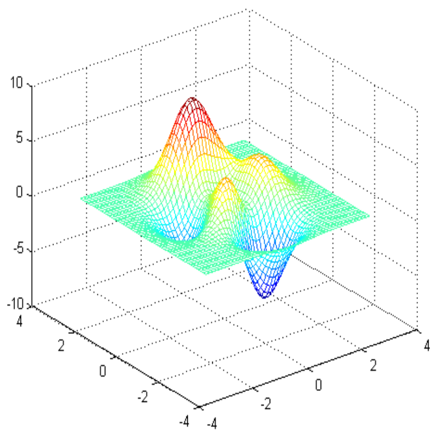
From Fig. 7-10, the dynamical evolution of spacecraft has been revealed, and essential characteristics of dynamics systems have been shown. In this paper, the China Space Station has been taken as an example, and coupled-structure vibration-attitude dynamics and control of spacecraft have been discussed. Under the condition of large degrees of deformation, it has been shown that spacecraft have a complex interaction between attitudinal movement and flexible-appendage vibration response.

Fig.1 The plate element[12] is a combination of the discrete Kirchhoff theory (DKT) plate bending element and a membrane element derived from the linear strain rectangular element with a total of 24 degrees of freedom (3 translations and 3 rotations per node). The piezoelectric strips are assumed to be perfectly bonded on the lower surface of the mirror and are modeled as a separate layer. The finite element model consists of 36 flat shell elements and 49 grid positions.

Fig.2 Simulation and Experimental Analysis Results:



(a)



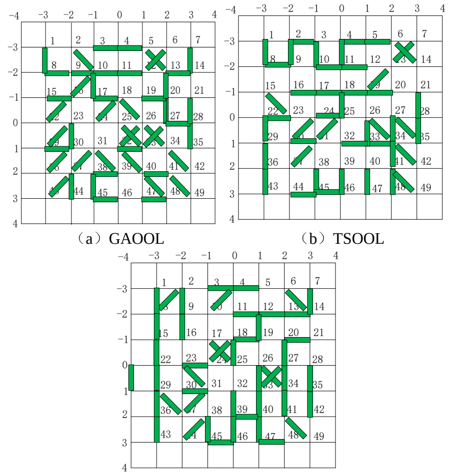
(b)

(a) a fixed–fixed plate (b) distortion of the plate structure

Fig.3 Table 1 Strain data

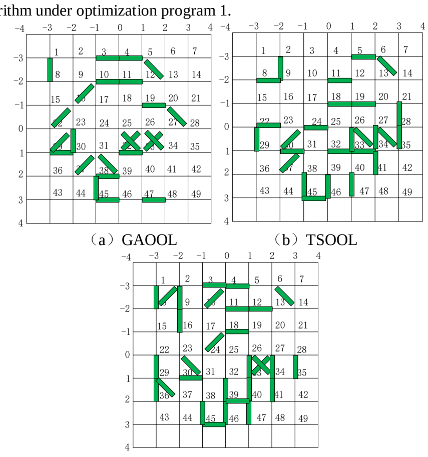
	-3	-2	-1	0	1	2	3
-3	0.0001	0.0034	-0.0299	-0.2450	-0.1100	-0.0043	-0.0000
-2	0.0007	0.0468	-0.5921	-4.7596	-2.1024	-0.0616	0.0004
-1	-0.0088	-0.1301	1.8559	-0.7239	-0.2729	0.4996	0.0130
0	-0.0365	-1.3327	-1.6523	0.9810	2.9369	1.4122	0.0331
1	-0.0137	-0.4808	0.2289	3.6886	2.4338	0.5805	0.0125
2	0.0000	0.0797	2.0967	5.8591	2.2099	0.1328	0.0013
3	0.0000	0.0053	0.1099	0.2999	0.1107	0.0057	0.0000

5. OPTIMAL RESULTS OBTAINED USING ARTIFICIAL INTELLIGENCE ALGORITHMS



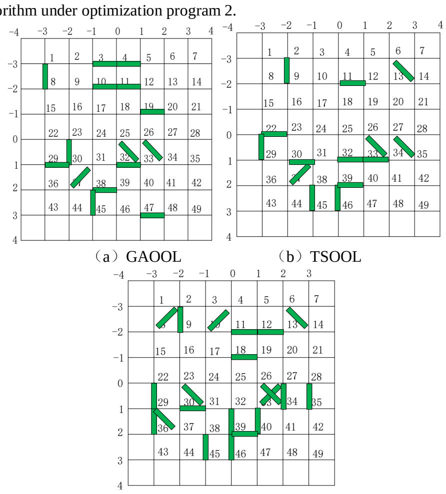
(a) GAOOL (b) TSOOL (c) ACOOOL

Fig 2 Optimal location and corresponding configuration direction obtained by the a) GAOOL algorithm under optimization program 1; b) TSOOL algorithm under optimization program 1; c) ACA algorithm under optimization program 1.



(a) GAOOL (b) TSOOL (c) ACOOOL

Fig 3 Optimal location and corresponding configuration direction obtained by the a) GAOOL algorithm under optimization program 2; b) TSOOL algorithm under optimization program 2; c) ACO algorithm under optimization program 2.



(a) GAOOL (b) TSOOL (c) ACOOOL

Fig 4 Optimal location and Fig 3 corresponding configuration direction obtained by the a) GAOOL algorithm under optimization program 3; b) TSOOL algorithm under optimization program 3; c) ACO algorithm under optimization program 3.

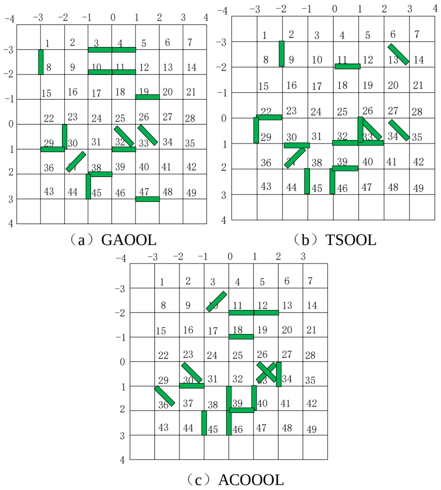


Fig 5 Optimal locations and corresponding orientations for the vibration response deformation obtained by the a) GAOOL algorithm and optimal control algorithm under optimization program 3; b) TSOOL algorithm and optimal control algorithm under optimization program 3; c) ACO algorithm and optimal control algorithm under optimization program 3.

6. CONCLUSIONS

In this paper, the optimal position and orientation of piezoelectric actuators and sensors for active vibration and shape control are considered. For each optimization problem, a modified optimization criterion is used. It is derived from the usual approaches, ensuring minimization of the deflection of the structure and accounting for the actuation system, which should enable less electrical energy to be used. An optimal control algorithm and twelve types of artificial intelligence algorithms are well adapted to solving these optimization problems, where the criteria are not convex and not easily derivable. Several applications are presented in the case of a plate-like structure. Simulations show the efficiency of the twelve types of algorithms for these optimization problems. The use of these algorithms allows us to easily account for the PZT orientations and locations in the optimization process. Numerical results demonstrate that the present algorithm can lead to light and optimum actuator positions and orientations that consume less electrical energy and enhance the structural shape control.

In addition, these methodologies have high computational efficiency, and there are no miscellaneous assumptions for them. If they can be used in practical engineering, they will be easy to adapt to arbitrary deformations of the plate-like structure, and we will still obtain the desired shapes. We know that some desired shapes are more difficult to achieve, but artificial intelligence algorithms can offer extra parameters, actuator orientations, and locations.

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