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Multi-modal control and position optimization of solar panels

Jingshuo Lyu

School of Transportation and Logistics Engineering, Wuhan University of Technology, Wuhan, China

326586@whut.edu.cn

Abstract. This paper investigates the impact of the position of piezoelectric actuators on the vibration control effect of the membrane plane composed of solar sail materials with a given unit area. Firstly, the nonlinear vibration equation of the membrane structure is perfected based on the system equation established by Yifan Lu et al. Then, the modal coupling effect pointed out by Liu Xiang is considered, and the fourth-order modal displacement generated by the piezoelectric actuator in vibration control is derived. Subsequently, the sliding mode controller used in vibration control is designed based on Lyapunov stability theory, and its effectiveness is verified through Simulink simulation. The sliding mode controller is used to calculate the required excitation signal and apply it to the piezoelectric patches. The reverse force is generated through the inverse piezoelectric effect of the patches to actively suppress the vibration of the solar sail. By changing the position and size of each piezoelectric actuator on the solar sail plane, this paper compares the impact of different layout positions on vibration control, and proposes an optimal layout scheme for the position of the piezoelectric patches in terms of control effectiveness.

Keywords: solar panels, nonlinear vibration, sliding mode control, position distribution of actuating areas.

1. Introduction

For such nonlinear systems of solar panels, piezoelectric cluster controllers have a wide range of application scenarios, including intelligent sensors and actuators, energy collection and conversion, structural health monitoring, acoustic applications, robotics, and biomedical engineering. For example, in large structures such as buildings, Bridges and aircraft, the piezoelectric cluster system can be used as a part of the structural health monitoring system to monitor the vibration, stress and other states of the structure in real time, so as to find out potential safety risks in time. Therefore, the study of piezoelectric cluster algorithm and control effect has important theoretical value, and has become a major research hotspot in the current academic circle.

In the design of piezoelectric controller of dynamic systems, many scholars have contributed methods such as sliding mode control and negative velocity feedback to the nonlinear vibration control of the system to solve practical engineering problems. For example, Peralta-Braz et al [1] designed a piezoelectric energy collector (PEH) based on the Kirchhoff-Love board theory and the isometric analysis (IGA) theory of bridge health detection, equipped with a particle swarm optimization (PSO) algorithm to maximize the control effect, the energy output of the signal. Using linear secondary regulator (LQR) for the active vibration control as the active controller, Liu, X et al [2] proved that the vibration of the film antenna is better suppressed by optimizing the position of the piezoelectric actuator. Yifan Lu [3] used Polyvinylidene fluoride (PVDF) actuator to control the large amplitude vibration of the film, and the control performance of the free vibration is compared by numerical simulation. The dynamic equation of nonlinear vibration of the film obtained in this paper provides an important reference for this paper. For the fourth-order mode nonlinear system, Liu Xiang [4] proposed to use the adaptive controller to suppress the large amplitude vibration of the membrane structure, which is more robust than the classical speed feedback controller. M.J. Mahmoodabadi et al [5] designed a 6 degrees of freedom (DOF) quad aircraft fuzzy fractional linear quadratic tracking (LQT) controller based on the multi-objective grey Wolf algorithm (MOGWA) optimization flight system to realize the control of the aircraft attitude. L. Dai et al [6] used the active control strategy of fuzzy sliding mode control (FSMC) to control the large amplitude vibration of a nonlinear elastic cable, which is suitable for the multimodal dynamic system described herein this paper, and its effectiveness is verified in numerical simulation.

In addition, in order to achieve a good effect on the system vibration control under the condition of reducing the layout cost of piezoelectric controller, some scholars compare the layout position of piezoelectric actuator in the system, or use intelligent optimization algorithm to explore the influence of controller position optimization on the piezoelectric control effect. Xinyi Lu [7] For the random nonlinear system with non-strict feedback, an adaptive neural inverse optimal output feedback controller is established, which realizes the goal of controlling the system inverse optimality and verifies the feasibility through examples. Adolfo Perrusquia et al [8] proposed reinforcement learning methods that mimic human empirical reasoning through an adaptive control strategy similar to the behavior of brain neocortex / striatum to address the problem of designing controllers of nonlinear systems. Vahid Fakhari [9] et al. considers the large amplitude vibration control using integrated piezoelectric sensor / actuator for functional graded material (FGM) plate under transverse mechanical load, adopts classical displacement-speed feedback control and robust H2 control, and discusses the influence of design parameters on the performance of the controller under the two control methods. Augusto H. Shigueoka et al [10] combines spatial and digital filter, and uses a piezoelectric sensor network to control the plate structure, while optimizing the closed loop of the position and gain of the electrical sensor. Kaiming Hu [11] For the multimodal vibration control system, proposed a cylindrical shell multimodal vibration average suppression method with the optimal distribution of piezoelectric sensor and motivator (S / As), using linear secondary Gaussian (LQG) controller with Kalman filter to control the response of the cylindrical shell under harmonic and transient excitation, so as to obtain better vibration control performance. Liu Xiang, CAI Guoping and other [12] used the position particle swarm algorithm to optimize the position of the piezoelectric actuator. The results show that the control effect of the linear secondary regulation piezoelectric actuator is deeply affected by the optimal position of the actuator, and its control performance is better than that of the non-optimal actuator. Based on the above vibration control study of the nonlinear system, it is found that the influence of the position of the piezoelectric actuator on the control effect is not deep enough. So this paper takes this as the research direction, and draws on the nonlinear vibration control design idea under the strong electric field condition of scholars[13][14].

2. Nonlinear Vibration Equation of Thin-Film Structures

This article abstracts the research subject of solar sails as a rectangular membrane structure with a Poisson's ratio of μ=0.4 and a density of ρ. Piezoelectric actuators generate bending moments through the application of control voltages, enabling precise and rapid motion control as well as nonlinear vibration control. They possess the advantages of compactness, lightness, high bandwidth, and high precision. The vibration control effect can be enhanced by altering the number of actuators. The relevant parameters of the membrane structure and piezoelectric controllers are provided in Table 2 of reference [3]. Among them, E_p and E_s represent the Young's moduli of the piezoelectric patch and solar sail, respectively; d_{31} and d_{32} are the capacitance of the piezoelectric actuator; h_p and h_s are the thicknesses of the piezoelectric actuator and membrane structure; and$\sigma_{0x} = \sigma_{0y} = 50$KPa represents the initial load on the membrane structure in the$x$and$y$directions.

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Assuming a uniform mass distribution of the material and neglecting the in-plane displacement of the membrane, the membrane structure equation can be derived from reference [3].

In the following equation, q_{ij} is the modal coordinate, and $\Phi_{Electric}$ is the modal shape function. This article considers the first four modes, setting *i* and *j* to 1 and 2.

Based on [3] and [4], by applying the Galerkin method to integrate over the entire area of the membrane, the nonlinear vibration equation of the thin-film structure can be derived as:

$$\ddot{q}_{ij} + 2\varsigma_0\omega_{ij}\dot{q}_{ij} + K_{ij}q_{ij} + f_{ij}\left(q_{gh}q_{rs}q_{uv}\right) + \Phi_{Electric} = P \qquad (1)$$

In the above equation, $g = 1{,}2, h = 1{,}2, r = 1{,}2, s = 1{,}2, u = 1{,}2, v = 1{,}2$.Where $f_{ij}\left(q_{gh}q_{rs}q_{uv}\right)$ is the nonlinear term, derived from reference [4], and ω_{ij} is the frequency of the external excitation.

3. Optimization design idea of piezoelectric controller position

As mentioned above, the particle swarm algorithm used by the [12] of Liu Xiang, Cai Guoping and others can quickly find the optimal solution in the multi-dimensional space by simulating the social behavior of the birds. This makes it particularly suitable for dealing with the complex multivariable optimization problems of piezoelectric cluster control system optimization, which has the advantages of strong global search ability, fast convergence speed, flexibility, good scalability and the ability to deal with complex nonlinear problems, and can meet the needs of the piezoelectric chip position optimization problems proposed in this paper.

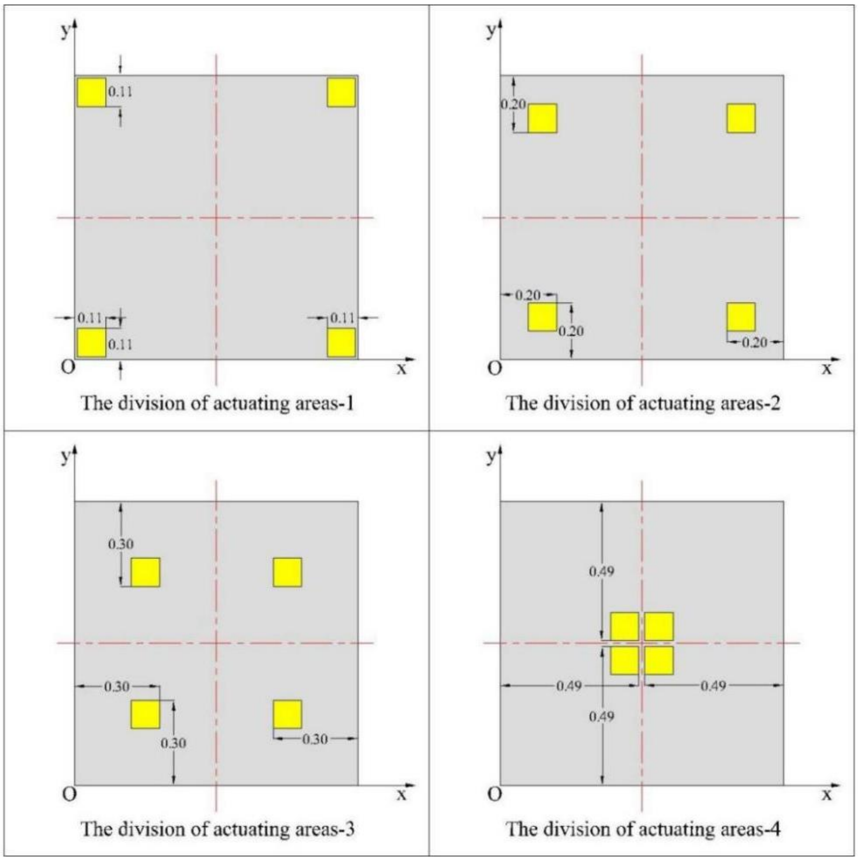

Figure 1. The division of actuating areas

In the optimization process, appropriate optimization criteria need to be defined, and the objective function should be able to quantify the vibration control effect of the sail plate under different piezoelectric actuator position layout. This paper considers the number, size and cost, and determines the position of the optimal setting position of the piezoelectric actuator on the solar panel through the simulink simulation experiment, so as to realize the effective control of the panel vibration. Finally, several layout positions are selected for comparative analysis, and the schematic diagrams of their positions are as Figure 1.

4. The influence of the change of the piezoelectric controller on the control effect

First, considering the case of the position-1 of the piezoelectric chip, by solving the differential equation of vibration control, the point displacement curve and the control voltage curve of each mode are obtained, as shown in Figure 2 and Figure 3 below. This study shows that sliding mode control (SMC) achieves fast convergence and better control effect in control performance.

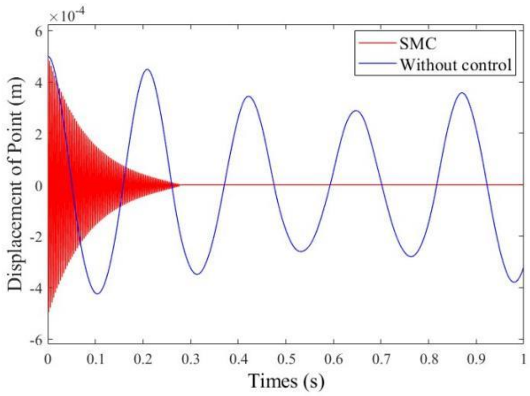

Figure 2. Comparison between SMC and Without control

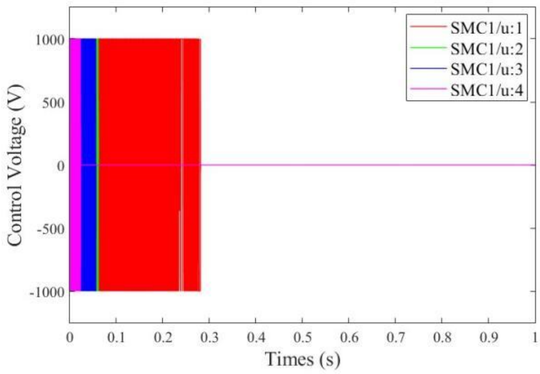

Figure 3. The control voltage of SMC

However, as can be seen from Figure 2 and Figure 3, in the process of deeply exploring the application of sliding mode control, the SMC controller produces relatively high and rapid change frequency of control voltage values during the operation process. This characteristic puts forward stricter requirements on the parameter setting of the piezoelectric controller to ensure the stability of the control system.

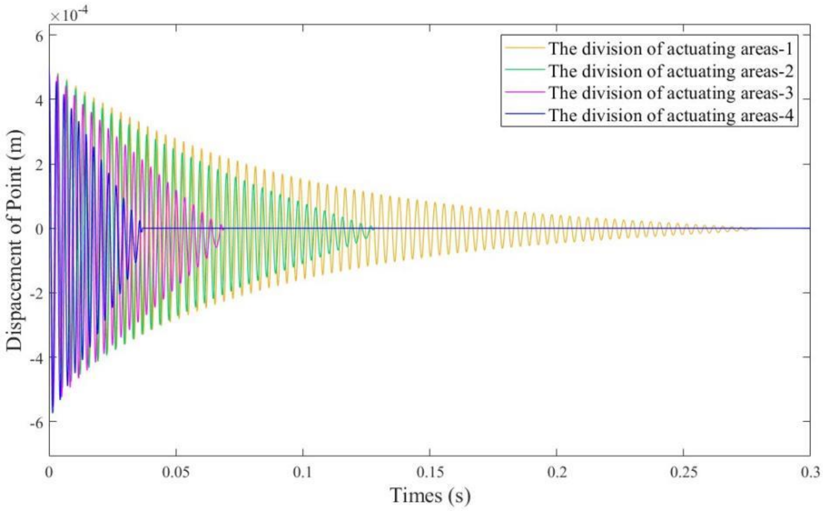

Figure 3. The Comparison between different actuating areas

Compared with the schematic diagram of Figure 1, the action positions of different piezoelectric controllers are studied. From the process of division of actuating areas-1 to division of actuating areas-

4, the layout position gradually converges to the film center of 1×1m. Combined with Figure 4, it can be observed that the closer the controller is to the center, the less time the control convergence using SMC, and the better the control effect.

5. Conclusion

In this paper, the method of synovial control is used to design the piezoelectric controller. In the nonlinear multi-degree of freedom vibration control system, one simulates the mode of each control film, in order to suppress the large vibrational displacement of the solar panel and cope with the film is continuously excited by external excitation. For the distribution of the piezoelectric actuator shown in Figure 1, the superimposed mode displacement curve is compared. The main conclusions are as follows: (1) if the piezoelectric plate size is the same and the control parameters of the sliding mode control are the same, changing the position of the piezoelectric actuator can significantly affect the control effect.(2) In the four cases in Figure 1, the closer the piezoelectric actuator is to the center of the sail, the faster the sliding mode controller can converge the waveform to a smooth speed, and the better the control effect. However, in this study, whether the conclusion (2) is applicable to other general conditions of the distribution position of the piezoelectric controller, and whether it is a general rule, still remains to be proved.

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