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Review of Actuator/Sensor Placement, Number and Configuration Direction Optimization

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1. Introduction

The optimization of actuators mainly includes several aspects, optimization of placement, number and configuration direction of actuators are most important. It has many important applications, such as vibration control, shape control, aeroelastic control etal. [1–3].

A typical actuator and sensor [4] location problem for structural vibration control can be described as a combinatorial optimization problem. The problem is based on the available information on the structure itself, on disturbances acting on the structure, and on the required structural performance. The preliminary information on the structural properties is typically obtained from a structural finite-element model. The disturbance information includes the disturbance location and disturbance spectral content. The structure performance is commonly evaluated through the displacements or accelerations of selected structural locations.

It is very difficult to duplicate the dynamics of a real structure during experiments and testing. This difficulty occurs not only because of a limited knowledge of disturbances or physical restrictions but also because the test actuators often cannot be placed at the actual locations of the disturbances and the sensors cannot be placed at locations where the performance is evaluated. Thus, to conduct the test close to the conditions of a structure in a real environment, we use the available placements of actuators and sensors and formulate the selection principals and selection mechanisms.

The controller design problem of a structure can be defined in a similar way. Usually, sensors are placed at the allowable sensor placements, which are usually outside the locations where the performance is evaluated. Actuators are located at the allowable placements, and they are not necessarily collocated with the placements where the disturbances are applied.

For simple experiment articles, an experienced experiment engineer can determine the appropriate actuator or sensor placements in a good way. However, when it is the first time testing large-scale and complex flexible structures, choosing the locations of the actuators and sensors is neither an obvious nor a simple task. In practice, heuristic means are combined with simplified analysis and engineering judgment to determine the placements of the actuators and sensors. In most cases, the placements vary during the experiments to obtain high quality data to identify the information of target modes.

In this paper, actuator/sensor optimization principals and actuator/sensor optimization methods are reviewed and discussed.

2. Body of abstract

This paper gives an overview of research on actuator/sensor placement, number and configuration direction optimization. First, the importance of the technology is introduced, and then, actuator/sensor optimization principals and actuator/sensor optimization methods are discussed. Finally, future research studies on technologies for intelligent optimization of the locations, numbers and orientations of actuators are recommended.

3. ACTUATOR/SENSOR OPTIMIZATION PRINCIPALS

Recently, several types of configuration principals for actuators/sensors have been proposed: those based on the configuration principal of the system energy, based on the configuration principal of the system vibration response, based on the configuration principal of system failure and reliability, based on the configuration principal of control/observation spillover, based on the configuration principal of system controllability/observability, and based on the configuration principal of other performance principals.

A. The Configuration Principal of System Controllability/Observability

From the above, it can be seen that the placement of sensors/actuators is the key factor of system controllability/observability. Although the number, size and configuration direction of the sensors/actuators can have a negative/positive effect on the controllability/observability of the system, related research has rarely been reported. On the other hand, the realization of multi-objective optimization [17] involves selecting one of the feasible solutions depending on the controllability/observability of the system; obviously, this is a complex problem, and further research needs to be done.

B. The Configuration Principal of the System Energy

From the above, it can be seen that the location of sensor/actuator plays a very important role in the vibration control system. In the same manner, although the number, size and configuration direction of the sensor/actuator can have a negative/positive effect on the energy dissipation [23] of the vibration system, related research has rarely been reported. On the other hand, the realization of multi-objective optimization requires us to select one of the feasible solutions depending on the maximization of the dissipation energy of the system. Obviously, this is an interesting and complex problem.

C. The Configuration Principal of the Vibration Response

From the above, it can be seen that the locations of sensors/actuators have an important influence on the vibration and shape control system. In the same way, although the number, size and configuration direction of the sensors/actuators can have a negative/positive effect on the vibration response of the vibration control system, related research has rarely been reported. On the other hand, the realization of multi-objective optimization requires us to select one of the feasible solutions depending on the vibration response of system; obviously, this is also an interesting and complex problem.

D. The Configuration Principal of System Failure and Reliability

From the above, it can be seen that the distributed parameters [28] of sensor/actuator have an important influence on the vibration and shape control system. There is no doubt that the number, size and configuration direction of sensors/actuators can have a negative/positive effect on the system failure and reliability of the vibration control system, but related research has rarely been reported. On the other hand, the realization of multi-objective optimization requires us to select one of the feasible solutions depending on the failure and reliability of the system; obviously, this is also an interesting and complex problem.

E. The Configuration Principal of Control/Observation Spillover

From the above, it can be seen that the placement of sensors/actuators has an important influence on the vibration and shape control system. There is no doubt that the number, size and configuration direction of the sensor/actuator can have a negative/positive effect on the control/observation spillover of the vibration control system, but related research has rarely been reported. On the other hand, the realization of multi-objective optimization requires us to select one of the feasible solutions depending on the control/observation spillover of the system; obviously, this is also an interesting and complex problem.

F. The Configuration Principal of Other Performance Principals

From the above, it can be seen that the placement, size and number of sensors/actuators have an important influence on the performance of the vibration and shape control system. There is no doubt that the configuration direction of the sensors/actuators can have a negative/positive effect on the performance of the vibration control system, but related research has rarely been reported. On the other hand, the realization of multi-objective optimization requires us to select one of the feasible solutions depending on the performance of the system; obviously, this is also an interesting and complex problem.

4. ACTUATOR/SENSOR OPTIMIZATION METHOD

Recently, several types of configuration principals for actuators/sensors have been proposed: the random class method, sequence method, inference algorithm, nonlinear programming optimization method, and intelligent algorithms.

A. Nonlinear Programming Optimization Method

From the above, it can be seen that the nonlinear programming optimization method can address some complex combinatorial optimization problem. In addition, this type of optimization method can be used to obtain high-accuracy results. However, the process of optimization costs too much time, and it does not have high efficiency in the control system. As a result, the nonlinear programming optimization method could not be used in a real-time control system, which may be one of the important reasons why related research in a real-time control system has rarely been reported. On the other hand, it is urgent to improve the computational efficiency of the nonlinear programming optimization method; this approach could help realize a multi-objective optimization of actuators/sensors.

B. Sequence Method

From the above, it can be seen that the sequence method can address some complex optimization problems. In addition, this type of optimization method is easy to realize because it is usually used in a linear system. However, the process of optimization also costs a large amount of time, and it does not have high efficiency in a control system. As a result, the nonlinear programming optimization method could not be used in a real-time control system, which could be one of the important reasons why related research in a real-time control system has rarely been reported. On the other hand, it is urgent to improve the computational efficiency of the nonlinear programming optimization method; this approach could help realize the multi-objective optimization of actuators/sensors.

C. Inference Algorithm

From the above, it can be seen that the nonlinear programming optimization method can address some complex combinatorial optimization problems. In addition, this type of optimization method can be used to obtain high-accuracy results. However, the process of optimization costs too much time, and it does not have high efficiency in the control system. As a result, the nonlinear programming optimization method could not be used in a real-time control system, which could be one of the important reasons why related research has rarely been reported. On the other hand, it is urgent to improve the computational efficiency of the sequence method, and this approach could help realize the multi-objective optimization of actuators/sensors.

D. Multi-objective Optimization Algorithm

From all of the above, we can find that multi-objective optimization of actuators/sensors has been research 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 done. In addition, the above algorithms' optimization time is usually too long, and they are not suitable for application of real-time vibration and shape control systems.

E. Intelligent Algorithms

From the above, it can be seen that the intelligent algorithms can address some multi-objective and complex combinatorial optimization problems. In addition, this type of optimization method can be used to obtain more high-accuracy results. However, the performances in the process of optimization in terms of elapsed time are different among the different types of intelligent algorithms. Some of the algorithms have high efficiency with regard to the control system. As a result, intelligent algorithms must be chosen before they are used in real-time control systems. This aspect could be one of the important reasons why related research has rarely been published. As a result, intelligent algorithms have priority for use in engineering practice.

5. RECOMMENDED FUTURE RESEARCH

Most previous research has only focused on the actuator placement problem in structure vibration control; however, the acting force's effect direction has usually been ignored. Obviously, if a piezoelectric actuator can have a better effect in a certain direction, then a better effective result would be obtained, and a control method could be changed into vector control. As a result, some scholars [62–66] are interested in solving the actuator/sensor placement, number and configuration direction optimization problem using intelligent algorithms. In the future, the control of a flexible multi-body system composed of plate-like structures has application to the control of space systems and aircraft, to name a few. Flexible multi-body systems composed of plate-like structures are typically lightweight and highly flexible. These systems have distributed-parameter dynamics, their natural damping is very small, they have many densely packed low-frequency modes; and their model parameters are uncertain. Moreover, performance requirements, such as the pointing accuracy, shape control, and bandwidth, are very stringent and make the problem of structural vibration more acute. Examples of flexible multibody systems composed of plate-like structures include a variety of space structures ranging from large solar panels to very complex space stations. Future research will be concerned with the intelligent high precision shape and vibration control of flexible multi-body systems composed of plate-like structures. The dynamics of flexible multi-body systems composed of plate-like structures is uncertain due to factors such as high nonlinearity, consideration of higher modal frequencies, high dimensionality, multiple inputs and outputs, and operational constraints, as well as unexpected failures of sensors and/or actuators. The research will address the modeling of these flexible multi-body systems composed of plate-like structures and the associated vibration and shape control systems with a new type of intelligent controller design technique. Most importantly, the development of aircraft and enormous flexible multi-body systems has become a research focus in the field of flexible multi-body dynamics and control, such as the space mirror and space solar power station. The technologies for intelligent optimization of the locations, numbers and orientations of actuators will speed up the development of manmade vehicles, reduce the cost and risk of operations, and enhance support for future space activities greatly. There is no doubt that they will play a key role in future research on spacecraft and further exploitation of outer space. Acknowledgment

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