



Comparison of various decentralised structural and cavity feedback control strategies for transmitted noise reduction through a double panel structure



Jen-Hsuan Ho^{a,*}, Arthur Berkhoff^{a,b}

^a Department of Electrical Engineering, University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands

^b TNO Technical Sciences, Acoustics and Sonar Acoustics, P.O. Box 96864, 2509 JG Den Haag, The Netherlands

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ABSTRACT

This paper compares various decentralised control strategies, including structural and acoustic actuator–sensor configuration designs, to reduce noise transmission through a double panel structure. The comparison is based on identical control stability indexes. The double panel structure consists of two panels with air in between and offers the advantages of low sound transmission at high frequencies, low heat transmission, and low weight. The double panel structure is widely used, such as in the aerospace and automotive industries. Nevertheless, the resonance of the cavity and the poor sound transmission loss at low frequencies limit the double panel's noise control performance. Applying active structural acoustic control to the panels or active noise control to the cavity has been discussed in many papers. In this paper, the resonances of the panels and the cavity are considered simultaneously to further reduce the transmitted noise through an existing double panel structure. A structural–acoustic coupled model is developed to investigate and compare various structural control and cavity control methods. Numerical analysis and real-time control results show that structural control should be applied to both panels. Three types of cavity control sources are presented and compared. The results indicate that the largest noise reduction is obtained with cavity control by loudspeakers modified to operate as incident pressure sources.

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1. Introduction

Traditionally, noise control methods are based on passive noise control, which means applying high damping materials, adding mass, adding resilient elements or installing absorbing resonators in the system. Passive noise control can effectively reduce noise at high frequencies [1,2]. However, there is typically much less noise reduction at low frequencies, and reduction requires a substantial implementation cost because the acoustic wavelengths are much longer than the damping structure [3,4]. Conversely, active noise control offers the potential advantages of decreased weight and better performance at low frequencies. With the development of smart materials and computational power, active noise control has received increasing attention in the past few decades. Traditional active noise control (ANC) for reducing broadband noise has been successfully applied in relatively small spaces [5,6]. However, for a larger control volume, the 3D wave propagation problem causes the control implementation to become too complicated and inefficient. Therefore, active structural acoustic control (ASAC) was

* Corresponding author. Tel.: +31 53 489 2842; fax: +31 53 489 1060.

E-mail addresses: j.ho@utwente.nl (J. Ho), a.p.berkhoff@utwente.nl (A. Berkhoff).

proposed to simplify the control computation. ASAC can simplify a 3D problem to a 2D problem by directly controlling the vibrating structure to reduce the structure's radiating sound pressure instead of addressing 3D acoustic wave propagation [6,7]. Furthermore, for a large configuration, decentralised control or distributed control can make the controller suitable for practical implementations [8–12]. Moreover, the remarkable performance of the decentralised feedback control strategy for the broadband objective has been observed [13]. A double panel structure, which consists of two panels with air in the gap, is another common implementation for noise reduction. The double panel structure offers the advantages of low sound transmission at high frequencies, low heat transmission, and low weight [1,14–16]. Piezoelectric materials have been investigated and applied frequently for vibration control of smart structures because of the compact dimensions and rapid response of these materials [5,11,17]. In this paper, a double panel structure with multiple decentralised feedback control is investigated. Various structural and cavity control strategies are applied to this system to reduce the amount of noise transmitted. A structural–acoustic coupled model is developed, and the dominant structural/acoustic modes of the double panel structure at resonance frequencies are analysed. The panel control principles in the double panel structure are incorporated in the structural–acoustic model and are validated with a real-time control implementation. Several control strategies based on identical control stability indexes are compared to find the optimal control method, which leads us to further investigate various cavity control strategies. The principal contributions of the present paper are the detailed investigation and comparison of the various decentralised structural and cavity feedback control strategies in double panel structures, all of which are based on identical control stability indexes.

This paper has four main sections. Section 2 describes a multichannel decentralised feedback control system for a fully coupled plant matrix and a method for control stability analysis. Section 3 describes our numerical model and the experiment measurement set-up. Section 4 presents and discusses the detailed investigations of the structural control, cavity control, combination control and comparisons. Section 5 provides a control performance comparison of various cavity control sources.

2. Control method

2.1. Multiple decentralised feedback control

Fig. 1 illustrates the signal block diagram of a feedback control system. $\mathbf{e}(j\omega)$ is the error signal matrix, where ω is the angular frequency [rad s^{-1}] and $j = \sqrt{-1}$. $\mathbf{G}(j\omega)$ is the plant transfer matrix; $\mathbf{u}(j\omega)$ is the control signal matrix; $\mathbf{d}(j\omega)$ is the noise source matrix, which is the error signal without the input control signal; and $\mathbf{H}(j\omega)$ is the control matrix, which is a constant $\mathbf{H}$ in this paper. The time-dependent signals are the real part of the complex vectors (i.e., the time-dependent error signal $\mathbf{e}(t) = \text{Re}\{\mathbf{e}(j\omega)e^{j\omega t}\}$).

From the block diagram in Fig. 1, $\mathbf{e}(j\omega)$ can be derived as

$$\mathbf{e}(j\omega) = [\mathbf{I} + \mathbf{G}(j\omega)\mathbf{H}(j\omega)]^{-1} \mathbf{d}(j\omega), \quad (1)$$

where $\mathbf{I}$ is an identity matrix. To present the physical interactions between each control unit in a multiple-input and multiple-output (MIMO) control system, a fully coupled multiple channel plant transfer matrix $\mathbf{G}(j\omega)$ is applied:

$$\mathbf{G}(j\omega) = \begin{bmatrix} \mathbf{G}_{11}(j\omega) & \cdots & \mathbf{G}_{1m}(j\omega) \\ \vdots & \ddots & \vdots \\ \mathbf{G}_{l1}(j\omega) & \cdots & \mathbf{G}_{lm}(j\omega) \end{bmatrix}, \quad (2)$$

where $\mathbf{G}_{lm}(j\omega)$ is the transfer matrix from the m -th actuator to the l -th sensor.

2.2. Control stability

In theory, the stability of a feedback control system can be unconditionally guaranteed when the sensors and actuators are dual and collocated [18]. Therefore, the control gain can be increased infinitely to decrease the error signals of Eq. (1) to

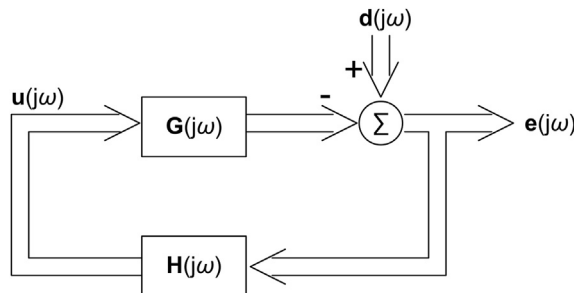


Fig. 1. Direct velocity feedback systems.

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