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A STUDY ON THE ARRANGEMENT OF ACTUATORS AND SPEAKER ZONES OF THE PANEL SPEAKER

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ABSTRACT

When the vibration of the thin panel by exciting single point is used to radiate sound, the inherent vibration characteristic of the plate itself causes influence on the radiated sound. A conventional panel speaker system usually uses the single or double point excitations for generating the sound through the panel itself. The radiated sound can be easily distorted due to the modal characteristics of the plate so it is difficult to expect sufficient sound power or high radiation efficiency. In this paper, to achieve an immersive sound field, the multiple speaker zones on a thin panel are created with the limited number of actuators. The designated vibration field which can generates directional sound is realized by employing the vibro-acoustic inverse rendering methods. Actuators are arranged from the positions which have the advantage of implementing with multi-modal excitations. The location and number of actuators are compared with the location and number of controllable speaker zones. Numerical simulations are conducted for a thin rectangular panel to compare the results in the viewpoint of the solution stability, the input efficiency, and the acoustic performance.

Keywords: *Vibro-acoustic inverse method; panel speaker; vibro-acoustic rendering; virtual speaker;*

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1. INTRODUCTION

In traditional audio-visual (A/V) devices, the picture and sound emerge from different locations due to the limited area for components. The thinner and lighter the device, the narrower the space especially where the speaker unit is installed. It is related with not only a decrease in immersion but also insufficient sound power and low quality. A thin panel can be virtually converted into a set of speaker and baffle by using actuator array at the periphery of the panel [1,2]. One of commercial devices, called 'CSO'[3], produce a stereo sound directly from the TV screen by using actuators on the left and right-side of the back panel. Because it can only vibrate the area where the actuator is located, it is impossible to create a freely-positioned speaker zone which vibrates with a high amplitude. In this paper, one can find that the speaker zone can be operated by actuators which is not a coincident location and a larger number of speaker zones can be generated than that of actuators.

2. THEORETICAL BACKGROUND

To compare the performance characteristics in generating When excitation is given at a certain location, elastic wave will propagate through a structure in all direction from the driving point as a traveling wave. If one uses such waves, the relationship between input signals of excitations and velocity responses can be written in a matrix form as

$$\mathrm{G}_{p\times N}\mathrm{A}_{N\times 1}=\mathrm{V}_{p\times 1} \tag{1}$$

Here, p denotes the number of observation points, N the number of actuators, A the matrix of input voltage signal, V the matrix form of target vibration field, and G the transfer functions matrix between input signals of excitation actuators and vibration responses.

Because the transfer matrix, G, is changeable corresponding to the boundary condition of the system, the measured frequency response function by experiment is to be employed. To obtain proper magnitude and phase weightings to be provided to the actuator array, an inverse technique can be utilized. Complex actuator weightings, E, can be calculated by using the matrix G and the rendered vibration field V as follows:

$$\mathrm{A}_{N\times 1} = \mathrm{G}^{\dagger}_{p\times N}\mathrm{V}_{p\times 1} = \left(\mathrm{G}^{H}\mathrm{G}\right)^{-1}\mathrm{G}^{H}\mathrm{V} \tag{2}$$

Here, G^H is the conjugate transpose of the matrix G [4, 5]. In the inverse estimation of the actuator weightings, the system becomes usually ill-posed, and the obtained solution can be unstable. Therefore, the regularization method is needed to remove such instability in inverse process. In this work, Tikhonov regularization technique [6] is adopted as

$$J = \left(\mathrm{V} - \mathrm{GA}_F\right)^H\left(\mathrm{V} - \mathrm{GA}_F\right) + \beta \mathrm{A}_F^H \mathrm{A}_F \tag{3}$$

$$\mathrm{A}_F = \left(\mathrm{G}^H\mathrm{G} + \beta\mathrm{I}\right)^{-1}\mathrm{G}^H\mathrm{V} \tag{4}$$

where J is the cost function for solving the minimization problem. J consists of the error between target field, V, and rendered vibration pattern, GA_F, and the weighted input power. Here, A_F implies the regularized input voltage signal, and β the weighting constant for input power.

3. NUMERICAL SIMULATION

3.1 Simulation condition and rendered target field

To validate the present method, a thin, flat, homogeneous, and isotropic supported aluminum plate is used for the numerical simulation. The dimensions of the plate are 1.69 m in length, 0.95 m in width, and 3 mm in thickness. The material properties of the panel are as follows: density, 2700 kg/m^3; Young's modulus, 70 GPa; Poisson's ratio, 0.33; loss factor, 0.3. The boundary condition in the practical situation is usually not easy to precisely define; in this work, a simply supported boundary condition is assumed. A total of 20 actuators placed at the periphery of the plate with 300 mm spacing in length and 400 mm spacing in width are used for a formation of virtual speaker as shown in Fig. 1.

In this research, radiated sound power, which can be obtained by using Rayleigh's integral of the velocity information on the plate surface [7,8], is considered as a performance by varying the location of virtual speaker. Desired vibration filed is composed of speaker zone with the vibration amplitude which can radiate 90 dB (SWL) and the other baffle zone with no vibration amplitude.

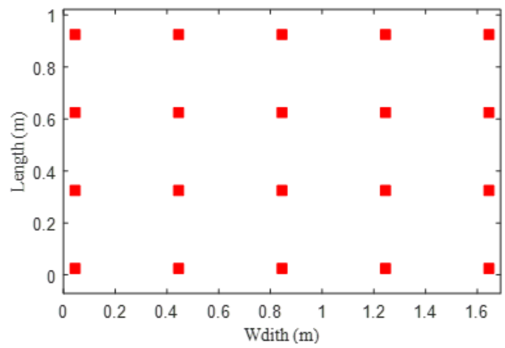

Figure 1. Actuator locations for generating a virtual speaker on the thin panel.

3.2 Simulation results

Figure 2 shows the reconstructed vibration field by varying the virtual speaker position with the proposed method. One can find that the control target is not just generating the high amplitude vibration at the speaker zone, but also the vibration at the other zone should be suppressed simultaneously. It is also observed that the virtual speaker zone can be generated properly at the position where is not matched with the actuator location. Although there are a few of unnecessary vibrations in the generated field depending on the virtual speaker location, a number of virtual speaker zone can be formed which is larger than the number of actuators.

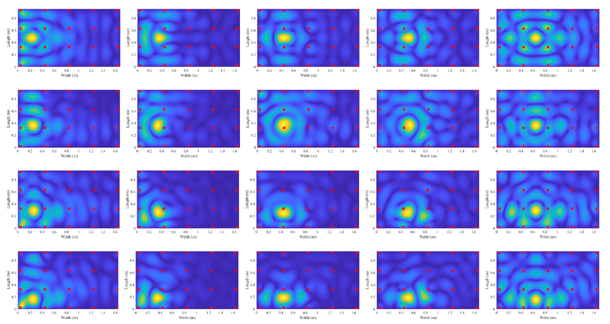

Figure 2. Generated vibration field by varying the center position of the virtual speaker zone within a quarter of the panel.

To minimize the actuator weightings which are related to the input effort or input energy, Tikhonov regularization is adopted. The total input power consumed by actuators to adopt the regularization technique for control is reduced to 25%.

4. CONCLUSIONS

In this work, a few of 20 actuators located at a thin plate is employed to generate a number of the rendered target patterns using the vibro-acoustic inverse method. It is found that the regularization is effective in obtaining the effective input effort. It is also noted that in-phase vibration control can be obtained at speaker zone. Because the present method is very simple in its concept, it can be implemented as a practically useful method for generating a complicated, localized vibration field in a structure.

5. ACKNOWLEDGMENTS

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