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DESIGN AND IMPLEMENTATION OF ALGORITHMS FOR ACTIVE CONTROL OF MULTI-MODAL NOISE IN DUCTS

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ABSTRACT
For a few years, studies concerning the active control of the noise radiated by fans in ducts have been multiplied thanks to the increasingly powerful processors. This paper presents a modal controller reducing the tonal noise due to higher order modes. This allows simultaneous and independent reduction of the pressure of each mode at each frequency. Notch filters have been implemented and compared to the classical FXLMS algorithm. Simulations have shown their performance concerning the computational time. Results are presented with the use of a variable stepsize algorithm. This method optimizes the convergence time and reduces instabilities when local minima are not well detected by the system. These algorithms have been experimentally tested to reduce the sound emitted by an axial fan used as a ventilation system in aircraft cabins with the use of a MIMO controller.

1 - INTRODUCTION

During the last decades, advances in control algorithms have allowed many applications concerning the reduction of the propagation of sound in ducts. Mainly of these results use the well-known Filtered-X Least Mean Square (FXLMS) algorithm, applied to the plane wave propagation. More recent works have been published for example by Stell and Bernhard [1], concerning the reduction of the sound due to higher order modes in ducts. Silcox [2] and Chan [3] have worked on the reduction of the broadband noise generated by crowns of loudspeakers mounted on the duct, in simulations. Among the existing experimentations based on a MIMO control, we can mention Besombes [4] and Sutliff & Al [5], who have implemented the classical FXLMS algorithm. We discuss here on the reduction of the acoustic pressure emitted by an axial fan. The sound generated downstream in the waveguide is constituted of the superposition of a broadband and a tonal noise, relative to the blade passage frequency. The reduction of this tonal noise radiated downstream in the circular duct is firstly obtained with a modal control approach of the classical FXLMS algorithm. These first results have been then improved with the use of notch filters and a variable stepsize algorithm, in order to reduce the computational time and to stabilize the system.

2 - MULTI-MODAL CONTROL STRATEGY

As the primary source is multi-modal, we have performed a modal controller corresponding to a transformation between the measured response in physical coordinates and the desired response in modal coordinates. If the undesired noise is composed of Q significative modes at K frequencies, the system is composed of $Q \times K$ single-input, single-output (SISO) controllers (fig. 1), where MR and MD are the modal reconstruction and decomposition. The controller size is independent of the number of error sensors U and transducers V. The filter outputs $y_{q,k}$ and the coefficients $w_{g,q,k}$ are given by

$$y_{q,k}\left(n\right)=\sum_{g=1}^{G}w_{g,q,k}\left(n\right)\cdot x_{k}\left(n-g\right) \tag{2}$$

$$w_{g,q,k}\left(n+1\right)=w_{g,q,k}\left(n\right)-\mu_{q,k}\cdot e_{q}\left(n\right)\cdot r_{q,k}\left(n-g\right) \tag{3}$$

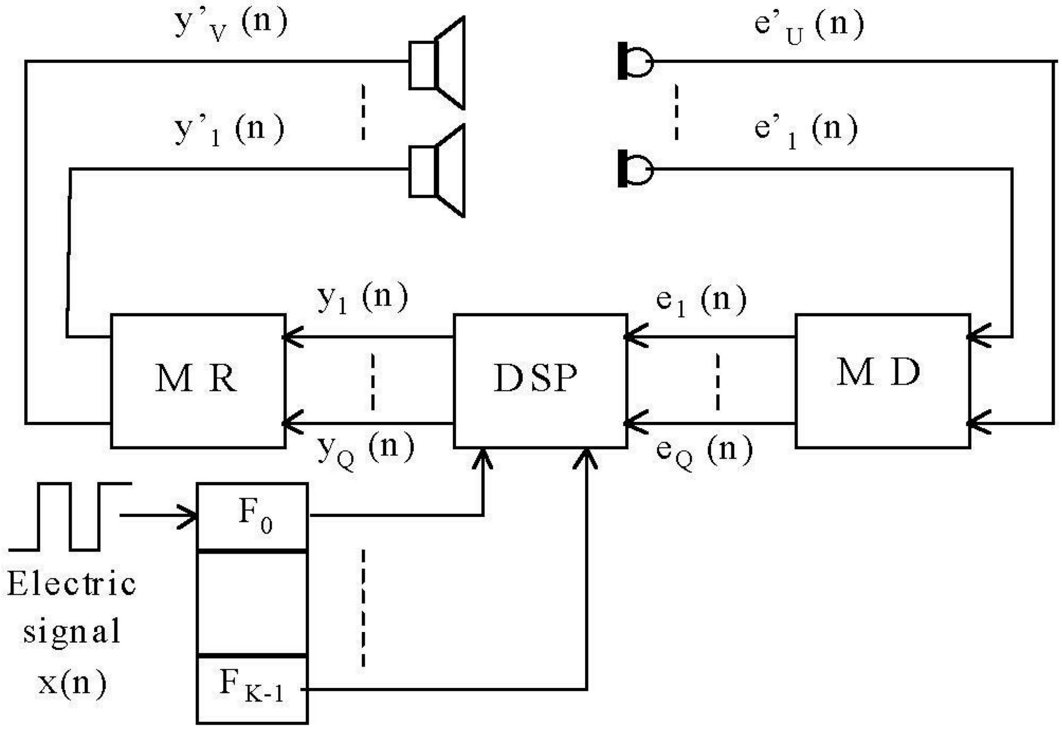

Figure 1: Principle of the modal controller.

where G and H are the control and identification filter orders, and the filtered reference signals $r_{q,k}$ include each series of coefficients $\widehat{C}_{h,q}(n)$ estimating the real modal error paths.

3 - SIMULATIONS

3.1 - Notch filter

Considering modal cross-coupling effects in circular ducts, the classical FXLMS algorithm has been firstly implemented (figs. 2-a, 2-b). Equivalent results for the control of the (1,0) mode are not shown here. As the primary source is a tonal noise, it is possible to implement a notch filter. For each frequency and each mode, two reference signals $x_I(n)$ and $x_Q(n)$ in phase and in quadrature, are used to update the coefficients $w_I(n)$ and $w_Q(n)$ [6].

$$y(n) = w_I(n) \cdot x_I(n) + w_Q(n) \cdot x_Q(n) \tag{4}$$

Figures 2-c, 2-d give the same reduction of the modal error signals, and the computational time of the control phase needs only $K \times Q(2 \times 2 + H)$ iterations instead of $K \times Q(2 \times G + H)$.

3.2 - Variable stepsize algorithm

As the signals received at the error sensors are liable to be submitted to temporal fluctuations, it is interesting to update the stepsize in terms of its fluctuations [7], with the relations

$$\mu'(n+1) = \alpha \cdot \mu(n) + \nu \cdot e^2(n) \tag{5}$$

$$\mu(n+1) = \begin{cases} \mu_{\max} & , \mu'(n+1) > \mu_{\max} \\ \mu_{\min} & , \mu'(n+1) < \mu_{\min} \\ \mu'(n+1) & , \text{ otherwise} \end{cases} \tag{6}$$

Simulations show that the variable stepsize attains rapidly a maximum. It converges then towards an asymptotic value (fig. 3).

4 - EXPERIMENTATIONS

The fundamental frequency of the 10 cm diameter axial fan studied here is about f_0=2150 Hz. The control acts here on the reduction of the (0,0) and (1,0) modes at the first two frequencies. Two crowns of four loudspeakers and four sensors have been mounted on the duct, in order to fully describe the (1,0) rotating mode in the cylindrical duct, decomposed into two pseudo modes (1,0)+ and (1,0)−. The sound

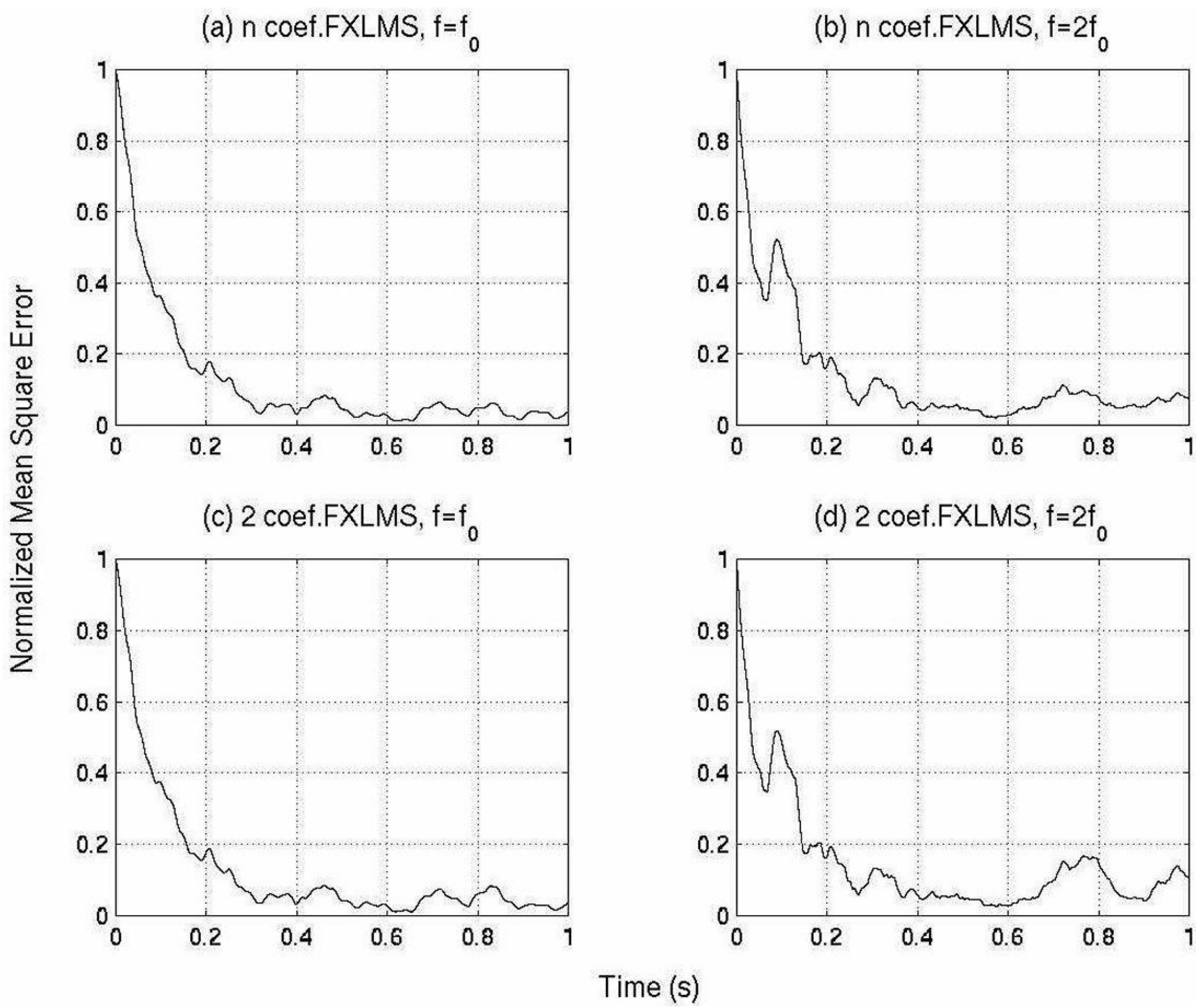

Figure 2: Comparison of the n-coef. FXLMS and the notch filter.

pressure levels corresponding to the modal errors $e_{(0,0)}$, $e_{(1,0)+}$ and $e_{(1,0)-}$, reduced with the modal controller, are presented in fig. 4. The global sound pressure level has been attenuated of about 12 dB and 9 dB at the first two frequencies. Experimentations are now realized with the algorithms using notch filters and variable stepsizes, in order to optimize computational time and convergence speed.

5 - CONCLUSIONS

The transformation of the physical coordinates in modal coordinates has allowed the attenuation of the tonal noise due to the first two modes at the fundamental and the first harmonic, independently and simultaneously. This control can be extended to the general case, with the physical limitation of the duct size. If Q and/or K become important, each controller output can be function of a pair of coefficients linearly combined with the filtered reference signals in-phase and in quadrature. At present, experimental tests are led to compare the modal and the fully control methods. This latter does not depend on the modal decomposition inside the duct, which avoids the problem of mis-location, but is more exacting concerning the time of calculation.

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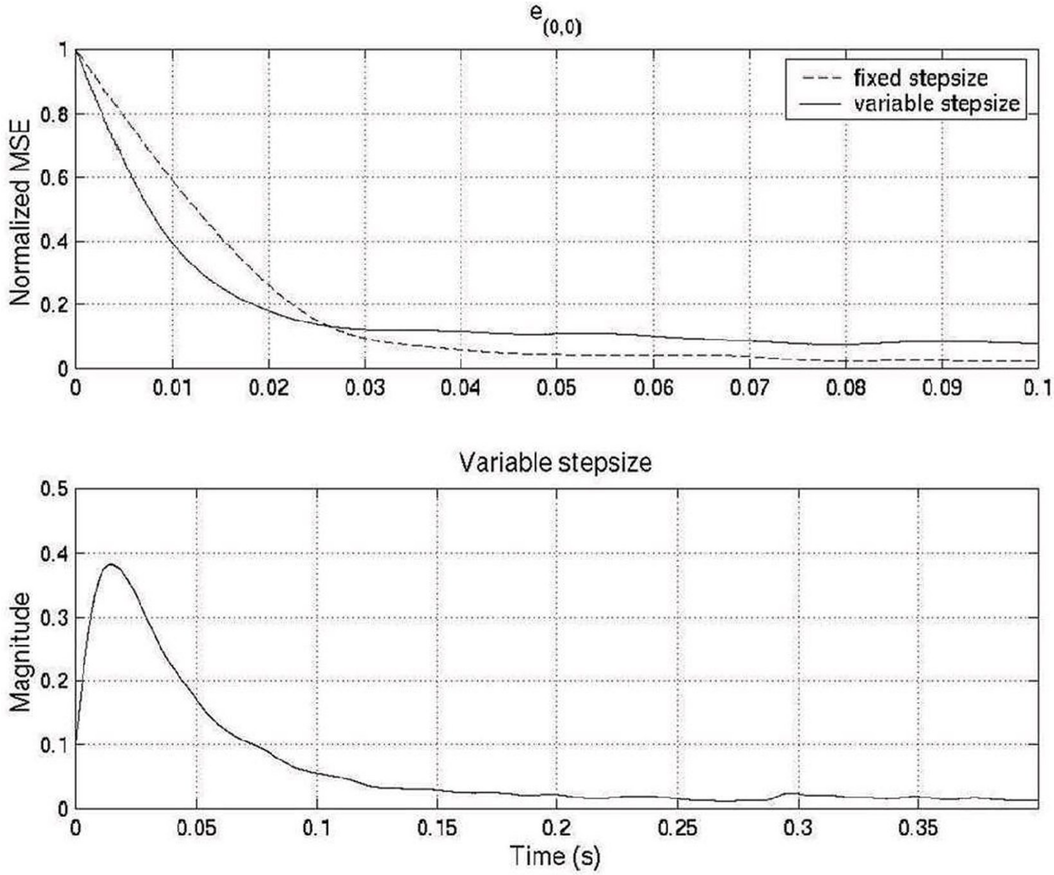

Figure 3: Comparison of the FXLMS algorithms with a fixed and a variable stepsize, at $f = f_0$.

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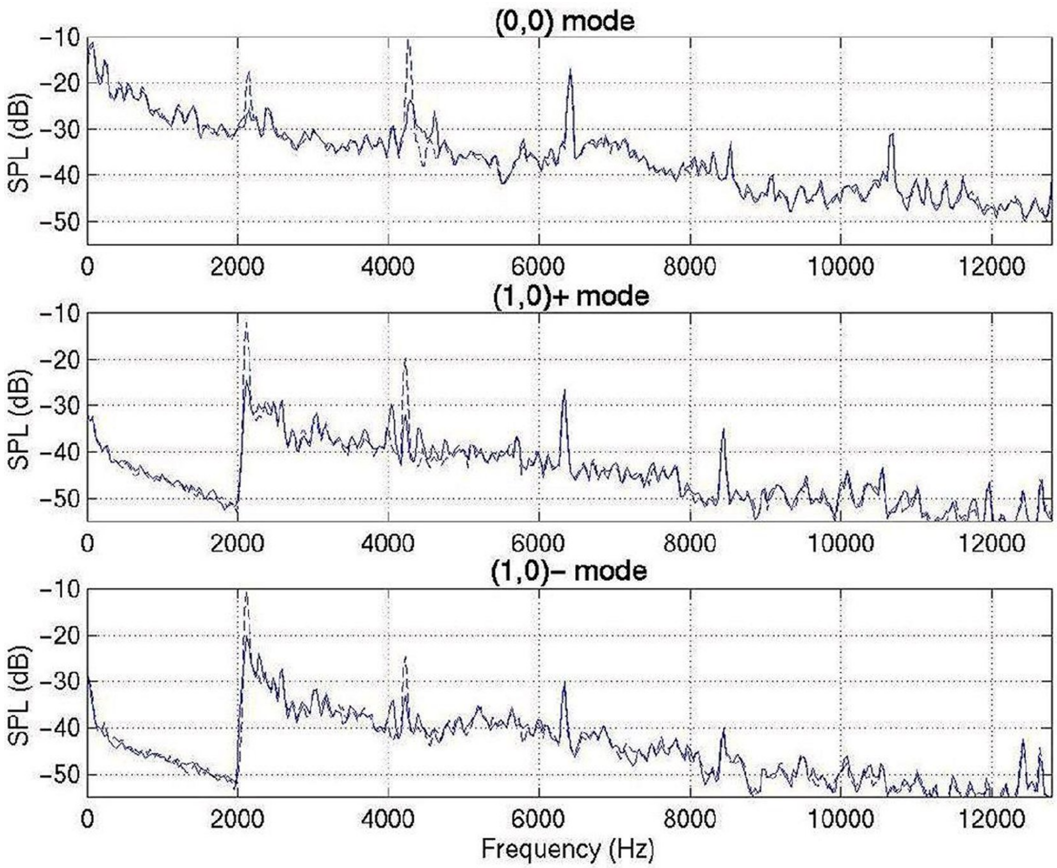

Figure 4: SPL of modal error signals with (solid line) and without control (dotted line).