inter.noise 2000
The 29th International Congress and Exhibition on Noise Control Engineering
27-30 August 2000, Nice, FRANCE

I-INCE Classification: 3.8

A 3D REAL-TIME ALGORITHM FOR ACTIVE SCATTERING CONTROL

E. Friot, M. Winninger, C. Bordier

CNRS-LMA A3, 31 Chemin Joseph Aiguier, 13402, Marseille, France

Tel.: +33 4 91 16 40 84 / Fax: +33 4 91 16 40 80 / Email: friot@lma.cnrs-mrs.fr

Keywords:
CONTROL, SCATTERING, EXPERIMENT, ALGORITHM

ABSTRACT

In this paper an arrangement of sensors and actuators as well as a real-time control algorithm are introduced as an approach to reducing the noise scattered from a reflecting body. The scattered noise is estimated from real-time measurements of the total noise around the body; an adaptive Least-Mean-Square algorithm taking feedback into account is used to minimize this estimate of the diffracted noise. 1D experimental results of reflection cancelling in a duct are given. 2D numerical simulations are also provided to assess the number of actuators and sensors required for effective control of the noise diffracted in all the directions.

1 - INTRODUCTION

Active Noise Control usually deals with reducing the *total* acoustic pressure but in some cases only the *scattered* noise has to be cancelled; such is the case of a hiding submarine impinged by waves from unknown enemy sources. In practice, sound sensors detect the total noise so the standard techniques of Active Noise Control (namely sensors and sources driven by an adaptive algorithm) are not appropriate for scattering. One solution consists in controlling the vibration of the body surface ([1], [2]) but this is difficult to achieve in practice. Directive sources can also be used ([3]) but they help to reduce the scattered noise in one direction only. In this paper, signal processing is used to compute the scattered noise from real-time measurements of the total noise. In this way standard microphones and loudspeakers as well as ANC usual algorithms such as the filtered-X LMS algorithm can be used for a truly 3D scattering control. Firstly in the paper it is shown that the scattered noise can be computed by linear filtering of the total noise around the reflecting body. The linear filter can be directly identified from off-line measurements prior to control. Secondly an adaptive real-time algorithm is introduced to achieve reduction of the scattered noise with secondary sources without prior information about the incident field. This algorithm was implemented in the LMA control hardware COMPARS; experimental results of scattering control in a duct are shown. Numerical simulations are also given for the 2D case to show how many noise sources and sensors are required for an effective noise control in all the directions.

2 - THE MIMO IMC-RMT-LMS CONTROL ALGORITHM

The acoustic pressure p outside a surface S enclosing a reflecting body can be written as:

$$p = p_{inc} + \int_S \left[G \nabla p \bullet \mathbf{n} - p \nabla G \bullet \mathbf{n} \right] dS$$

where G is the frequency domain Green function of the propagation medium and p_{inc} the acoustic pressure *in the absence* of the reflecting body; $\mathbf{n}$ denotes the outward vector normal to surface S. The well-known Green form above shows that the *scattered* noise around a reflecting body is a linear function of the *total* noise around the body. Furthermore this linear function does *not* depend on the primary field. For active control, this means that the scattered noise can be computed by linear filtering of the total noise around the reflecting body and that the appropriate linear filter can be merely deduced from preliminary off-line measurements with the control sources acting as primary noise sources. In practice the total pressure and pressure gradient around the body can only be measured at a finite set of sensor locations. Conversely cancellation of the scattered field or of its estimate can only be performed at a finite set of locations. Therefore neither estimation nor control of the scattered field can be perfectly performed in practice.

Since the scattered noise can be linearly deduced from the total noise around a reflecting body, an active device for scattering control can be made of an inner noise sensor ring and a source ring surrounding the body. An outer sensor ring can also be used for a preliminary off-line identification of the linear filter from total to scattered noise. The noise sensors provide reference signals for adaptive linear filters designed to minimize the estimated scattered noise. An X-LMS algorithm can be used to update the filter coefficients but feedback from the actuators to the sensors has to be removed from the adaptation loop; an efficient way to do this is to sum the sensor signals to build a single reference signal (see [4]). In this case the additional computations due to feedback remain low and the command signals can still be computed separately on a multi-processor hardware system. Figure 1 shows the way the controller works after identification of the linear filter from total to scattered noise. The sensor signals are used in two ways: they are summed up to provide a single reference for feedforward control after removal of the feedback path. The signals are also filtered to build estimates of the scattered noise which are used as minimization signals. In figure 1 all the transfer functions are identified off-line except adaptive filter **W**. The algorithm amounts to a filtered-X LMS algorithm with an Internal Model in the Controller to remove the feedback path; it also includes a filtering of the sensor signals such as in the Remote Microphone Technique designed to reduce noise at locations different from the sensor locations (see [5]).

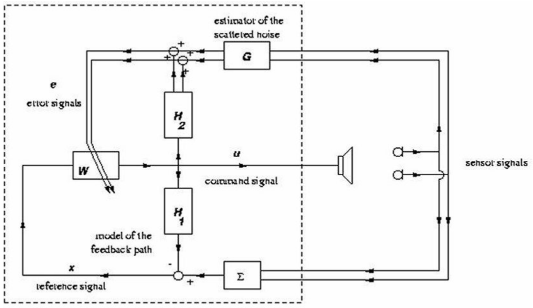

Figure 1: The adaptive scattering controller.

3 - 1D EXPERIMENTAL RESULTS

Active scattering control was implemented on the LMA hardware system COMPARS. Experiments were conducted in a duct with a reflecting termination in order to assess how well, in an academic set-up, the scattered field could be reduced. The primary noise was a 0-800Hz limited white noise; two sources and two minimization locations were used in order to avoid transmission zeros in the feedback path. Two microphones were also used upstream the noise sources for identification and assessment of the scattering in the duct. Figure 2 shows a Frequency Response Function which is the ratio between the signal at the first microphone and that at the second one. Without control, the FRF is typical of a reverberant cavity with frequency peaks in the response and 180° phase jumps. With control, the FRF is close to the one of a pure time lag with unity gain and linear phase, which is typical of sound propagation in an infinite duct. Scattering control performs impressively well.

4 - 2D NUMERICAL SIMULATIONS

In the multi-dimensional case, many noise sensors and sources are required to achieve scattered noise control in all the directions. In order to derive guidelines for choosing the number of sensors, numerical simulations were performed for an infinite cylinder impinged by pure-tone plane waves. A 32 acoustic ring was used for control as well as two 32-sensor rings. The cylinder radius was unity, the actuators were at radius 1.05, the inner sensor ring at 1.01 and the outer one at 1.1. For wave number k=10, figure 3a shows the far-field directivity pattern for the acoustic velocity of the scattered sound with and without minimization of the *exact* diffracted noise at the outer sensor locations; the incident plane wave comes from the right side and the modulus of its acoustic velocity is unity. The far-field scattered noise is reduced by more than 25dB; further computations show that the total noise is increased inside the noise sources ring only. Figure 3b shows the far-field directivity pattern with k=15. In this case the scattered noise is not reduced anymore in all the directions; 3 sensors per wavelength

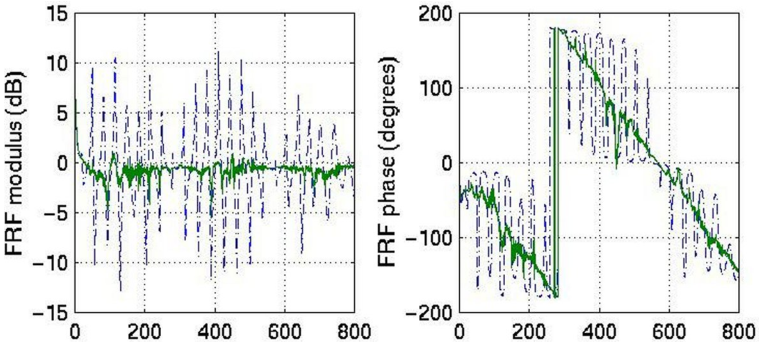

Figure 2: A longitudinal transfer function in the duct.

Figure 4a shows for k=10 the far-field directivity pattern of the scattered sound with and without minimization of the *estimated* diffracted noise at the outside sensor locations, the estimation of the scattered noises are built by linear combination of the total noises at the inner sensor locations. The incident plane wave direction was selected so that the scattered noise estimators were worst, by contrast to other directions where the estimator was excellent. Figure 4b shows the same directivity patterns for k=3. When the scattered noise has to be identified from the total noise, 10 sensors per wavelength are required for an efficient control.

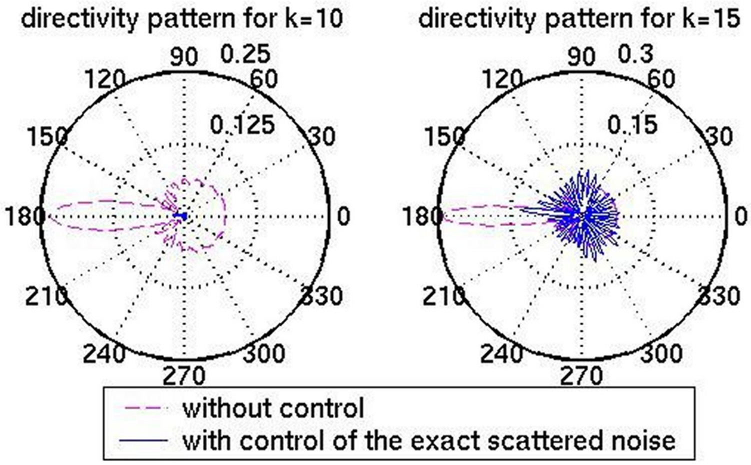

Figure 3: 2D scattered noises at radius ρ=100.

REFERENCES

1. **M. Furstoss and al.**, Surface impedance control for sound absorption: direct and hybrid passive/active strategies, *Journal of Sound and Vibration*, Vol. 203, pp. 219-236, 1997

2. **B. Nayroles and al.**, Conception of an active anechoic multi-cellular layer, In *ACTIVE 97*, pp. 1179-1188, 1997

3. **G. Mangiante and al.**, Auto-directive sources for 3D active noise control, In *Internoise 94*, pp. 1293-1298, 1994

4. **E. Friot and al.**, A parallel real-time algorithm for multi-channel feedback control, In *ACTIVE 99*, pp. 921-932, 1999

5. **A. Roure and al.**, The Remote Microphone Technique for Active Noise Control, In *ACTIVE 99*, pp. 1233-1244, 1999

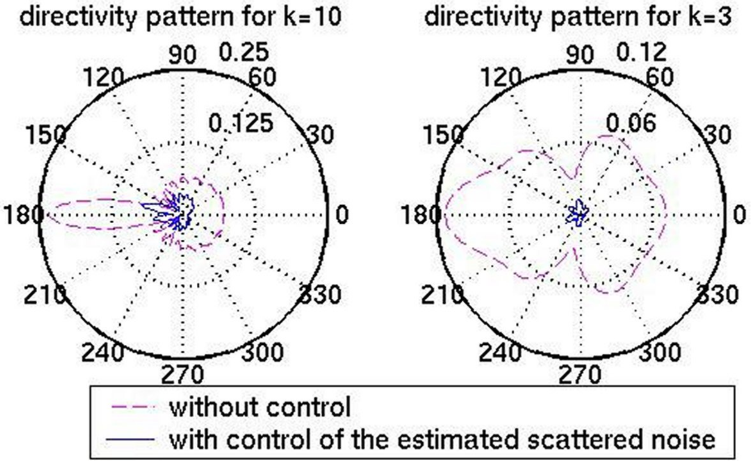

Figure 4: 2D scattered noises at radius ρ=100.