Application of the Genetic Algorithm to Real-Time Active Noise Control

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Abstract. A modified model, in the form of an FIR filter, is proposed for the modelling of the acoustic dynamics of an active noise control system. This is a low order filter formulation but consists of two independent elements—a time delay and a d.c. gain. Empirical data has shown that this model constitutes a good representation of the equivalent high order FIR filter and has the additional feature of being a high frequency noise filtering device. Because of its specific structure, the time delay and gain must be identified independently. This restricts the use of the conventional least mean squares technique for parameter optimization, as the cost function intrinsically comprises multimodal error surfaces. The use of Genetic Algorithms could be the best solution to address this issue but their unpredictable response in real-time require some special attention. A fully developed active noise control system, based on the Genetic Algorithm, to achieve the objective of noise reduction is described. To further guarantee the reliability of this approach, a supervisory scheme is incorporated for governing the real-time learning operations. A parallel hardware architecture, using two independent TMS320C30 digital signal processors, is designed for such implementation. The experimental results indicate that this approach to noise control is sound, and that noise reduction of more than 15dB(A) is consistently obtained.

Keywords: Active Noise Control, Genetic Algorithm, FIR Filtering, Parallel Real-Time Architecture

1. Introduction

Active noise control (ANC) employing real-time algorithms and architecture is a promising trend for future development and a number of systems have been proposed, as follows: ANC systems for power transformers (Cheuk, et al., 1994; Berge, et al., 1988), duct systems (Hall, et al., 1992; Park and Kim, 1993), systems for vehicle or flight cabins (Sutton, et al., 1994; Elliott, et al., 1990) and other noisy systems (Nelson and Elliott, 1993). The main contribution to the success of these systems has been the use of parameter identification techniques for the estimation of the noise dynamics in real-time and the adaptive optimal control laws that generate the corresponding anti-phase acoustic signals for the final noise cancellation.

In general, gradient descent least mean squares (LMS) techniques are often adopted for identification purposes. Despite the successful outcome of such conventional ANC systems, there are many shortcomings to use this approach. One obvious phenomenon is trapping at the local optima when the LMS optimization technique is employed. This often results in a sub-optimal noise reduction performance. Another deficiency is the modelling of the acoustic paths as well as the controller itself. These are usually restricted or over
dimensionalized in order to meet the required performance. Hence, the ANC system lacks real-time capability.

In this paper, a simple but modified finite impulse response (FIR) filter is proposed. This new model has two extra elements, a time delay and a d.c. gain. Because of its specific formulation, see eqn. (2), the common conventional least squares technique would be ill suited for the optimization of the cost function which has a multimodal error surface (So, et al., 1994). For Genetic Algorithms (GAs), on the other hand, this presents no problem.

The usefulness and maturity of GAs in technical applications have already been widely reported (Alander, 1994; Goldberg, 1994). In particular, knowledge-based systems using GAs have been successfully demonstrated (Baek and Elliott, 1993; Obavashi, 1995; Mackle, et al., 1995). In the domain of real-time complex control systems such as active noise control, the use of GAs is considered to be novel and will be shown as a promising approach for coping with the complexity of the noise signal.

To realize such a technical proposition in real-time, where both the speed and performance of the ANC system are of great importance, a dedicated real-time algorithm and computer architecture are required. A real-time LMS algorithm, based on a very low order FIR filter, is firstly implemented for the physical noise control. This scheme is then integrated with a parallel run time GA, operating on the modified FIR model, to improve its on-line performance. A supervisory scheme has been designed for the monitoring of both operations so that the noise reduction performance is guaranteed.

The organization of the paper is as follows: the formulation of the active noise control problem is outlined in Section 2. The real-time system is described in Section 3, while Section 4 provides the details of the genetic process for the modified FIR filtering model. This is followed by Section 5 where a description of a supervisory scheme to govern the two operations is presented. The effectiveness of the proposed scheme is demonstrated experimentally and the results are given in Section 6. Finally, the discussion and conclusion are contained in Section 7.

2. Problem Formulation

A generic feedforward type of ANC system is shown in Figure 1. It consists of four different parts: detector, error sensor, secondary source(s) and the controller. The detector and error sensor are electronic devices that are used for picking up the primary noise signal and error signal, respectively. The secondary sources, usually loudspeakers, are to generate the corresponding anti-phase signal for the noise signal, \( s(k) \).

The principle of noise cancellation is to ensure that the controller \( C(z^{-1}) \) produces the appropriate control signal \( u(k) \), according to the reference signal \( m(k) \), so that the resultant error signal \( o(k) \) is minimized. This can be done by taking the objective function \( J \) as the windowed mean square error, such that

\[
J = \min_{C(z^{-1}) \in \Phi} \left[ \frac{1}{N} \sum_{k=k_0}^{k_0+N-1} o^2(k) \right]
\] (1)

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