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Design and implementation of multichannel global active structural acoustic control for a device casing

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A B S T R A C T

The paper presents the idea and discussion on implementation of multichannel global active noise control systems. As a test plant an active casing is used. It has been developed by the authors to reduce device noise directly at the source by controlling vibration of its casing. To provide global acoustic effect in the whole environment, where the device operates, it requires a number of secondary sources and sensors for each casing wall, thus making the whole active control structure complicated, i.e. with a large number of interacting channels. The paper discloses all details concerning hardware setup and efficient implementation of control algorithms for the multichannel case. A new formulation is presented to introduce the distributed version of the Switched-error Filtered-reference Least Mean Squares (FXLMS) algorithm together with adaptation rate enhancement. The convergence rate of the proposed algorithm is compared with original Multiple-error FXLMS. A number of hints followed from many years of authors' experience on microprocessor control systems design and signal processing algorithms optimization are presented. They can be used for various active control and signal processing applications, both for academic research and commercialization.

1. Introduction

For numerous environments, structurally radiated noise from devices and machinery is a persistent problem. Passive barriers are often ineffective, particularly for low frequencies, or are inapplicable due to increase in size and weight of the device, and its potential overheating. An alternative way is to use active control methods [1–5].

Classical Active Noise Control (ANC) in three-dimensional enclosures encounters many problems related to complicated physical phenomena, generation of local zones of quiet instead of global reduction, high interference with the enclosure, and very high power consumption. However, if the noise source is separated from the environment by a thin wall or other structure, Active Structural Acoustic Control (ASAC) can be applied [6]. It aims at reducing noise propagation through the structure by controlling its vibration [7,8]. When appropriately implemented, it can result in a global noise reduction instead of local zones of quiet.

Such approach was successfully applied to single or double-panels in the literature [9–12]. However, before this project, there were neither reports in the literature, nor commercial products concerning active control of multiple walls of a device casing. Considering high practical potential of active control methods applied to enhance acoustic isolation of industrial devices and home appliances, confirmed by letters of intent from a number of companies, it motivated the authors to

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undertake this idea. To properly control required modes of the structure and reduce noise globally, a number of sensors and actuators was used. That involved a complicated multichannel plant with a number of interactions between its paths. To maintain scalability and cost efficiency of the proposed solution, a distributed control system architecture was preferred over a centralized one. However, it required to carefully design communication and synchronization schemes between units to fulfil the real-time demands, and to modify and efficiently implement the control algorithm, originally designed for a centralized system. Those are vital aspects for achieving the highest performance of active control systems. Hence, a new formulation is presented to introduce the distributed version of the Switched-error Filtered-reference Least Mean Squares (SEFXLMS) together with adaptation rate enhancement. It is shown that the distributed SEFXLMS exhibits the same final performance (noise reduction level) as the Multiple-error FXLMS, but it reduces the computational demand, at the expense of a reduced convergence rate. The convergence rate of the proposed algorithm is compared to the original Multiple-error FXLMS.

The aim of this paper is to present the whole idea of the active casing approach, to introduce a novel distributed version of the SEFXLMS algorithm and to share details of the hardware design and efficient implementation of the adaptive multichannel control algorithm. The performance of the proposed solutions is verified by an active noise control experiment. A number of hints followed from authors' experience is provided, which cannot be found in the literature. They can be directly applied by researchers and practitioners interested in designing and implementing complex active control systems. Also, readers from other fields of signal processing can find the proposed techniques useful for their applications.

The paper is organized as follows. In Section 2 a laboratory test rig in the form of an active device casing, equipped with sensors and actuators is described. Section 3 is focused on the control system architecture. Section 4 is devoted to control algorithms and their practical implementation. Section 5 presents a summary of conducted control experiments with the proposed hardware and algorithms.

2. Active casing

In this section, firstly the exemplary casing used in the research is introduced from the mechanical and vibroacoustical point of view. Subsequently, employed actuators and sensors are addressed.

2.1. Structure

For designing the structure of the experimental casing the following requirements have been defined:

- ease to change particular plates used as walls of the casing, in order to test a set of different thicknesses and materials of the plates;
- possibility to employ different actuators and sensors, dependent on chosen control strategy (AVC, ASAC, etc.);
- reduce interactions between walls.

These assumptions are fully realized in form of a box with a rigid frame, presented in Fig. 1. It consists of a 3 mm steel frame with screwed 1 mm walls of size 420 mm × 420 mm. As the source of disturbing noise within the enclosure, a speaker placed on the floor of the casing is used. It allows to treat the casing with signals most appropriate for the development and

Fig. 1. Photograph of the cubic casing with a rigid frame.