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CENTRALISED AND DECENTRALISED CONFIGURATIONS FOR PANELS WITH PIEZOELECTRIC ACTUATORS

Arthur P. Berkhoff[1,2], Johan M. Wesselink[2]

[1]TNO Science and Industry, IS-Acoustics
PO Box 155, 2600AD Delft, The Netherlands
arthur.berkhoff@tno.nl

[21]University of Twente, Faculty EWI
PO Box 217, 7500AE Enschede, The Netherlands

ABSTRACT

This paper discusses configurations for controlling broadband noise using piezoelectrically excited panels. The configurations can be distinguished by the physical layout and by the control structure. The physical layout of the system has some influence on the complexity of the control algorithms. For particular actuator/sensor combinations and a particular control objective, the control architecture can be decentralized, using very simple feedback or feedforward controllers, at small performance loss when compared to a centralized architecture. For some applications that require a different control objective, an additional centralized or possibly distributed architecture could be beneficial. A hardware realization with an associated control framework that allows the implementation of such a combined centralized-decentralized architecture is shown. Examples that are given are an embedded central control unit with all electronics in a single module and a centralized-decentralized architecture with partly decentralized hardware that is integrated with structural parts.

1 INTRODUCTION

Recent research in active structural acoustic control (ASAC) [1], in which structural actuators are used to control sound radiation, suggest that multiple decentralised feedback systems could be useful for noise reduction [2]. Such systems can be based on piezoelectric patch actuators and velocity sensors and a proportional feedback controller. If the actuator is small compared with the structural wavelength and if the velocity sensor is centered on the actuator then the system can be regarded as collocated, having minimum-phase behaviour with phase shifts between $-\pi/2$ and $\pi/2$. With proportional feedback, such systems are, in principle, unconditionally stable, even if multiple parallel control systems are used. It can be proven [2] that, for proportional feedback, the function of the control systems is to effectively remove mechanical power from the system; the decentralised control systems therefore add damping to the passive system. Practical implementations could be based on an accelerometer with an additional integrator and a controller with a certain amount of loop-shaping in order to improve performance and/or to improve robustness for non-ideal behaviour. Such systems primarily function as vibration reduction devices. Noise reduction can be a positive side-effect of such systems.

However, with respect to noise reduction performance of such systems, several questions arise. The first question is whether the reduction of noise radiated from such panels is guaranteed under all conditions. Reduction of the vibration of one part of a larger surface that radiates sound at low frequencies does not necessarily lead to a reduction of the radiated noise. Global noise reduction techniques using a centralised processor may be preferable in such cases, such as systems based on the identification of efficiently radiating, diagonalising vibration patterns [3]. Another question is whether the proposed decentralised system provides the most efficient solution for a given noise reduction in terms of actuator effort. Simulation studies by Scholte and D' Andrea [4], for example, show that a significant performance improvement over simple decentralised controllers can be obtained when a distributed controller is used, in which each local controller also receives information from adjacent controllers and adjacent sensors. In the latter paper, the performance is expressed in terms of noise reduction and required control effort. Another question is whether the decentralised system provides the most robust implementation for a given noise reduction.

Slight variations of the configuration also introduce new questions. One such question for example is whether the noise reduction performance is still sufficient if a strain sensor is used instead of a velocity sensor. In such cases an in-plane coupling between the actuator and sensor exists which could disturb the desired sensing of bending motion. Such a disturbance of sensing bending motion by in-plane coupling could reduce the effectiveness of the system for noise reduction applications. Systems with in-plane coupling for which significant noise reduction is desired would likely benefit from distributed control systems.

Another variation of the configuration is such that not the surface vibration level of the controlers itself, or the related noise radiation, should be reduced, but that the sound pressure level at a position remote from the panels should be reduced. If the sound pressure at that position is not uniquely determined from the transmission through all considered panels, then reduction of sound transmission does not suffice anymore. In such cases, certain panels should also act as loudspeakers. The latter case is almost allways relevant since, in the majority of applications, either the source can not be completely shielded from the receiver, the transmission paths from the source to the receiver are unknown, or the source is unknown. If the sound pressure at a certain location is to be reduced and if additional reference sensors are unavailable then it would also be beneficial to use acoustic sensors on the panels instead of velocity sensors. The acoustic sensors can be used to reconstruct the sound pressure at the intended position without doing phyiscal measurements at that position [5]. Also in such configurations, at least some coupling between the different control units is necessary, such as provided by a distributed controller or a fully centralised controller.

The above examples show that for certain very specific systems with very specific applications fully decentralised control can be useful. For the majority of applications however, a certain coupling between the different control units is convenient or even necessary. Such coupling issues are important for the decisions regarding cost-effective hardware. In general it can be observed that more centralisation is needed at lower frequencies and that fully decentralised systems often require relatively fast controllers with sufficiently small latency. In the following, a hardware architecture will be presented that enables the implementation of such combined decentralised/ distributed/ centralised systems.

2 HARDWARE ARCHITECTURES

2.1 Architecture for centralised control and local implementation of distributed/ decentralised control

Figure 1 gives an example of a configuration with a centralised controller connected to a series of distributed/ decentralised control units [6]. The central processor generally operates at lower sample rates than the distributed/ decentralised controllers. The distributed/ decentralised units perform local AD-DA conversion and local interpolation/decimation (Fig. 2). The central controller is able to control and monitor all actuators and sensors, respectively. Standard network protocols such as USB 1 , USB 2, or FireWire were found to be unsuitable for this application because of the large or unpredictable latency. Therefore, a dedicated low-latency protocol was implemented in order to enable feedback control and time-critical feedforward control over the network. Figure 3 shows the realisations of the central controller, the network interface for the central controller and a distributed/ decentralised controller, which, in this case, also contains the power amplifiers and analog sensor preconditioning, as well as interpolation/ decimation, AD-DA conversion, and the network interface.

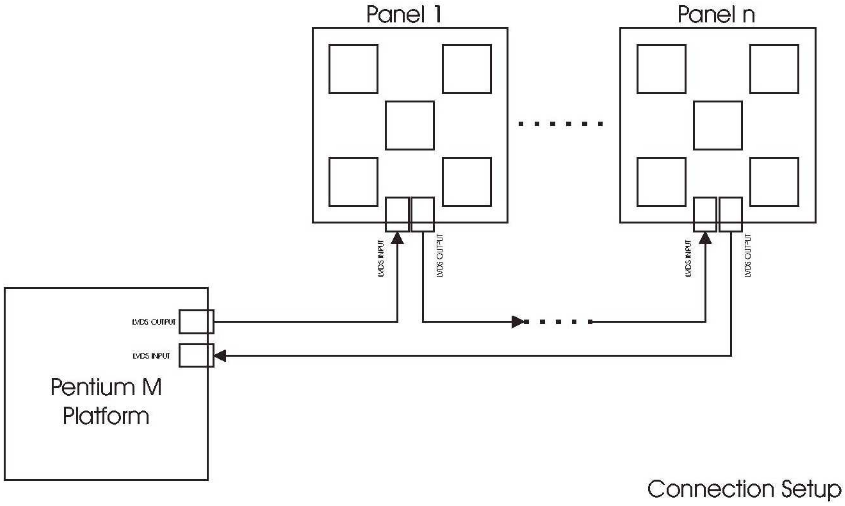

Fig. 1. Central controller and decentralised/ distributed control units connected by a digital high-speed network.

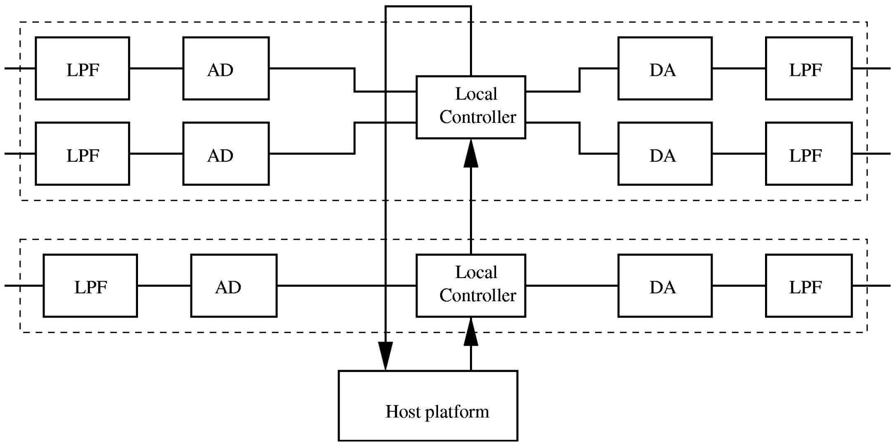

Fig. 2. Configuration of the local controllers with local AD-DA conversion, local interpolation/ decimation filtering and connection with the centralised controller.

Fig. 3. Central controller and network interface for connection to the decentralised/ distributed controllers (left); decentralised/ distributed controller with integrated power electronics (right).

2.2 Hardware architecture for centralised control with integrated hardware for decentralised/ distributed control

Figure 4 gives an example of a central CPU controller based on an Intel Mobile architecture. An extension module provides all AD-DA conversion and filtering for 16 input channels and 16 output channels. Filtering is performed digitally on FPGA. The filters are fully programmable, enabling a careful tradeoff between minimum group-delay and maximized stop-band attenuation. The system also supports jitter-free sub-sample delay sample mode, leading to a further reduction of the system latency. A comparison between regular one-sample delay mode, sub-sampe delay mode without jitter-elimination (feedthrough mode), and the jitter-free sub-sample delay mode is provided in Fig. 5. For this system an RT-Linux based operating system is used; the control systems are developed from Simulink, using a real-time implementation with the Matlab RealTime Workshop.

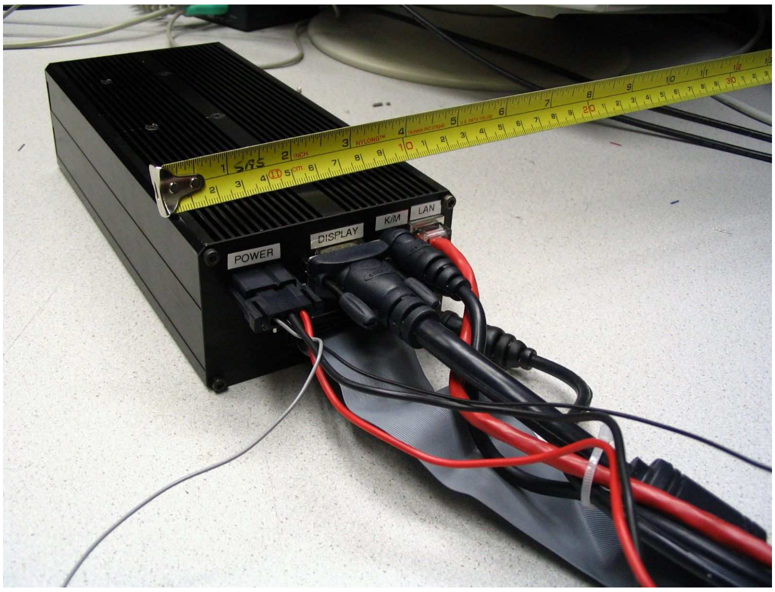

Fig. 4. Centralised controller with integrated 16-channel AD and 16-channel DA conversion, interpolation/ decimation, and possibility for integrated high-speed distributed/ decentralised control.

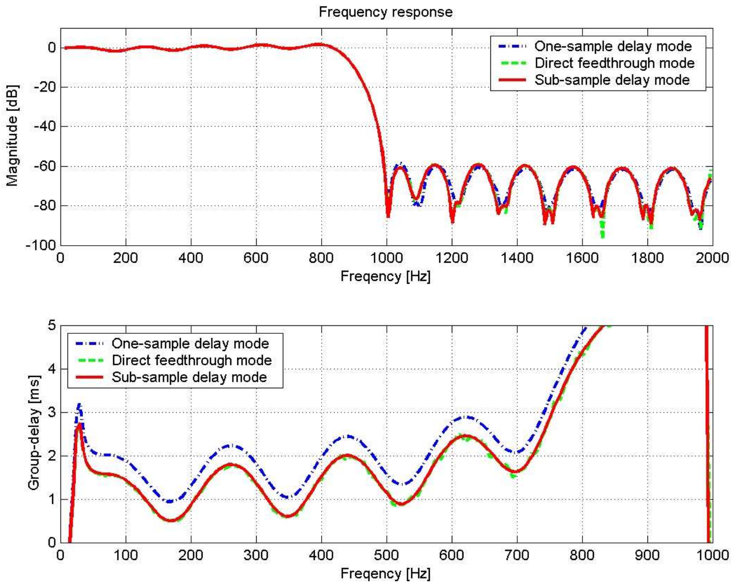

Fig. 5. Control system transfer characteristics. Magnitude and group-delay of minimum-phase interpolation/ decimation filters for three different sampling modes.

3 CONCLUSIONS

A hardware architecture for combined centralised/ distributed/ decentralised control configuration has been presented. Two different implementations of such an architecture have been shown.

4 ACKNOWLEDGEMENTS

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REFERENCES

[1] C.R. Fuller, S.J. Elliott and P.A. Nelson, *Active Control of Vibration*, Academic Press, 1996.

[2] S.J. Elliott, P. Gardonio, T.C. Sors and M.J. Brennan, Active vibroacoustic control with multiple local feedback loops, *J. Acoust. Soc. Am.* **111,** pp. 908-915, 2002.

[3] A.P. Berkhoff, Broadband radiation modes: Estimation and active control, *J. Acoust. Soc. Am.* **111**, pp. 1295-1305, 2002.

[4] E. Scholte and R. D' Andrea, Active vibro-acoustic control of a flexible beam using distributed control, Proc. of the American Control Conference, pp. 2640-2645, 2003.

[5] A.P. Berkhoff, Control strategies for active noise barriers using nearfield error sensing, *J. Acoust. Soc. Am.* **118**, pp. 1469-1479, 2005.

[6] J.M. Wesselink, A.P. Berkhoff, G.J. Laanstra and H. Kuipers, Implementation issues of a high-speed distributed multi-channel ADDA system, 2005 International Workshop on Acoustic Echo and Noise Control IWAENC.