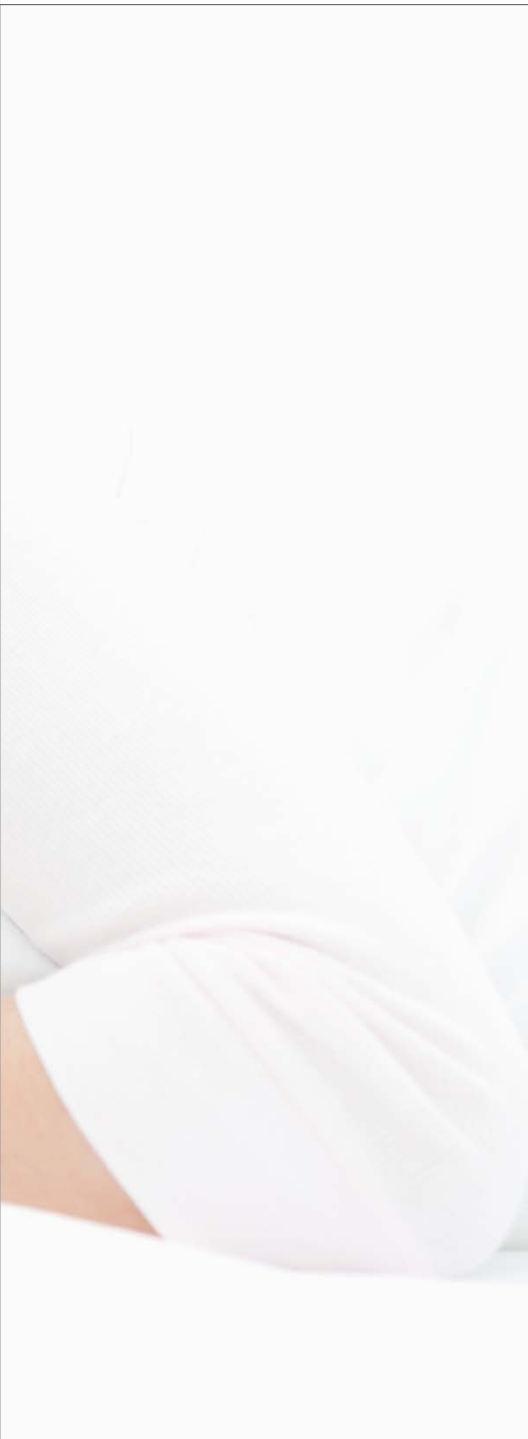
Active noise reduction in the home

Sound Asleep

Researchers at the Helmut Schmidt University/University of the German Federal Armed Forces in Hamburg are working on systems for actively canceling out sound – for example, to reduce the levels of traffic noise in residential buildings. This requires a computation-intensive adaptive algorithm, which they implemented on a dSPACE DS1006 Processor Board.



Noise Pollution

Exposure to the noise all around us, especially in towns, is stressful and can cause illness. Homes can be soundproofed, but even the best insulating materials are useless if a window is even only slightly opened for ventilation. Moreover, the insulation becomes less efficient as the sound frequency decreases (i.e., low tones or increasing wavelength). A bass sound wave of 100 Hz (such as the deep growl of a truck's diesel engine) has a wavelength of just under 3.5 m. Sound waves like these go straight through commonly used insulating layers a few centimeters in thickness.
It is for these scenarios that the Helmut Schmidt University/University of the German Federal Armed Forces in Hamburg, funded by the German Federal Foundation for the Environment (DBU), developed an active noise reduction system that works even at low frequencies and with a window open.

Eliminating Noise with Anti-Noise

Active sound reduction is based on the principle of destructive interference, in which two opposite-phase waves cancel each other out (figure 2).
The canceling sound wave is computed from measurements made by two microphones: one that measures the noise signal near its source, and another that measures the signal resulting from the superposition of sound waves and canceling sound waves. However, total elimination of all noise is scarcely possible because sound propagates in all directions, and the measurements taken at the source of the noise are themselves affected by the canceling wave. Moreover, the noise also reflects off the walls, creating a complex sound field. Finally, noise usually consists of a broad range of frequencies for which no precise canceling signal can be generated (or only very locally at best).

Active Noise Reduction in the Home

The experiment setup (figure 3) for the noise-cancellation system developed at the Helmut Schmidt University consists of two rooms: a low-reflection outer room where the sound waves and canceling sound waves are generated, and an inner room whose acoustic properties are typical of a room in a residential building. This connects to the outer room via a standard, off-the-shelf

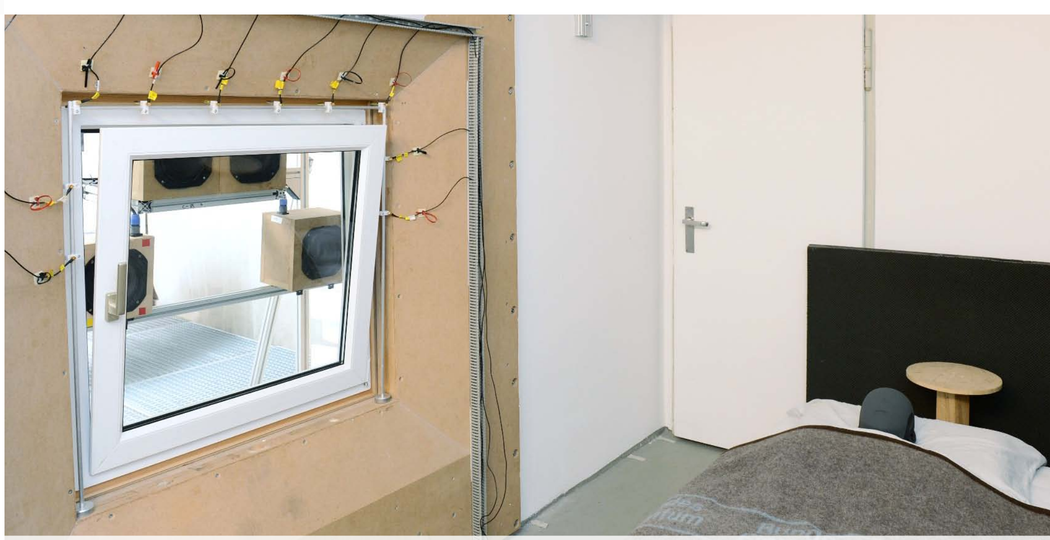


Figure 1: Noise-cancellation speakers reduce the noise before it reaches the window (third project phase).

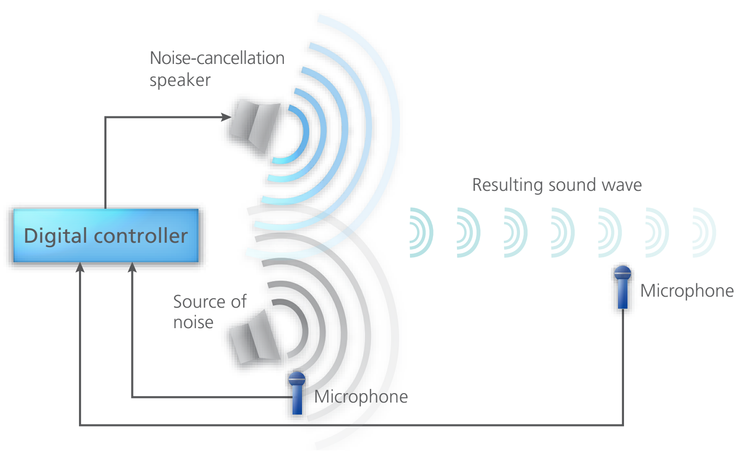


Figure 2: The principle of active noise reduction: The original sound wave (grey) and the canceling sound wave (blue) are superimposed and (almost) eliminate each other (cyan).

window and has to be protected against too-high noise levels.
The signals of the error microphone (the "error" is the residual noise, which ideally needs to be reduced to zero) are passed via a dSPACE DS2004 High-Speed A/D Board to the DS1006 Processor Board, which computes the output signals with an adaptive, digital control algorithm (the filtered-x least-mean-square or FxLMS algorithm). The output signals are output via a DS2102 D/A Board, then passed through a low-pass filter, amplified, and finally passed to the noise-cancellation speakers. In some experiments, there is also a reference microphone that measures the noise directly at the source.

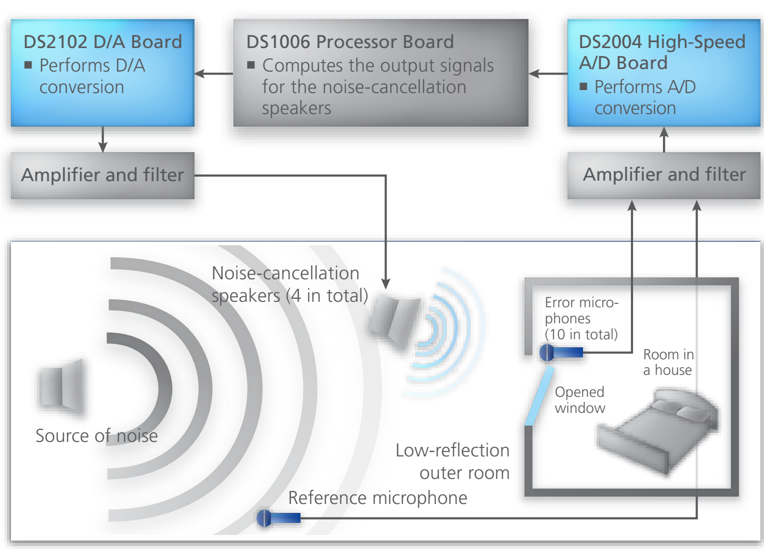
Details of Signal Processing

The requirements for signal processing speed are very high because the canceling sound wave has to be generated by the time the noise reaches the noise-cancellation speaker. In the short time that the noise takes to travel to the speaker (approx. 0.6 milliseconds for 20 centimeters), the input and output signals have to pass through the amplifier and the analog anti-aliasing filter, and the FxLMS algorithm has to calculate the output signals. In multichannel systems, the algorithm consists of a digital, adaptive finite impulse response (FIR) filter for each noise-cancellation speaker and additional FIR filters that represent the acoustic path between each noise-cancellation speaker and each error microphone (secondary paths).
Thus, the setup described here, with 4 noise-cancellation speakers and 10 microphones, has 4 FIR filters for the control and 40 FIR filters for the secondary acoustic paths. Each FIR filter corresponds to one convolution operation. As the number of filter coefficients increases, so does the number of multiplications. The filters need a certain number of coefficients to deliver good control results, however, because they represent pulse responses that are physically present. The higher the sampling rate, the more filter coefficients are required, and the less time is available to compute them.

Enlarging the Zone of Silence

In the first project phase*), active noise reduction was performed by means of two error microphones in a pillow and two speakers at the head of the bed (figure 4). The noise reduction was about 18 dB, but it was spatially very restricted. In the second project phase, the zone of silence was enlarged by using additional speakers and microphones and optimizing their positions. This setup is not very practical in real life, however, so the aim of the third

Figure 3: Schematic of the experiment setup for the canceling sound wave experiment.



*) Funded by the German Federal Foundation for the Environment (DBU) in several projects between 2006 and today.

> "With the high processing power of the DS1006 Processor Board, it was no problem to increase the sampling rate of the noise-cancellation system from 2 kHz to 8 kHz. Full utilization of multitasking will provide further reserves for improving the control."
>
> *Sergej Jukkert, University of the German Federal Armed Forces in Hamburg*

project phase was to muffle the noise directly at the window (figure 1). This "active sound blocker" works with a reference microphone that measures the noise at the source, and also uses speakers and microphones directly on the window frame. This greatly reduced the noise (by 16 dB) in a mean frequency range of 80 Hz to 480 Hz, as measured at twenty measurement points distributed throughout the room.

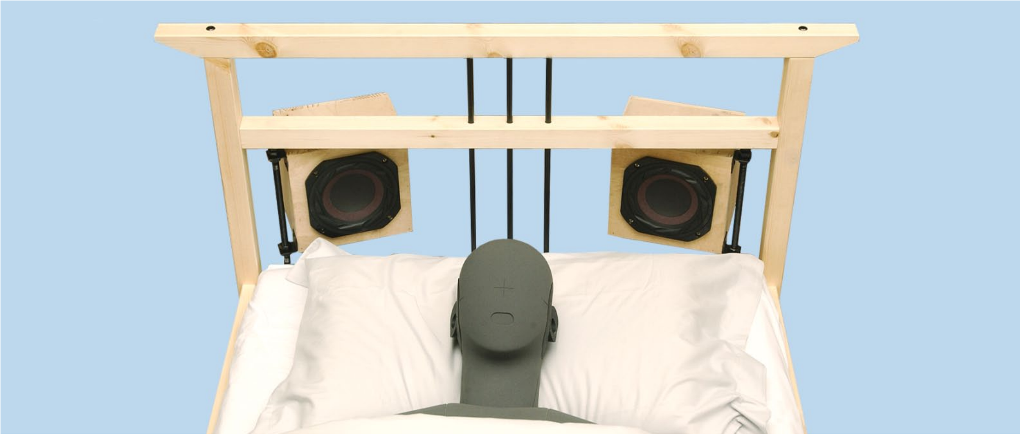


Figure 4: Noise-cancellation system directly at the head of the bed (first project phase).

From Lab to Home

In collaboration with Adaptronics International GmbH, work is currently being performed on other practical aspects. The aim is to remove the reference microphone as well as to integrate the speakers and microphones in the window frame. In this new control concept, a reference signal is generated from the error signal internally. Because this delays the generated signal as compared with the noise signal, high execution speed is even more important. The speed was already increased from 2 kHz to 8 kHz with the same number of channels, though there is not yet a sufficient number of filter coefficients. The current focus is therefore on distributing the control algorithm across all four cores of the DS1006 board. Controller concepts that calculate model parts in the frequency range are also being investigated. This will make it possible to increase the number of filter coefficients and further improve control quality. ■

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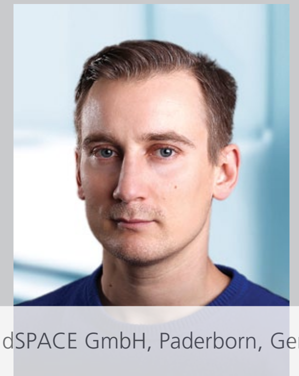

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