Broad-Band Active Noise Reduction In Communication Headsets By Digital Feedforward Control

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1.0 Introduction

Communication headsets are frequently required to operate in environments in which acoustic noise interferes with the intelligibility of speech. The noise reduction obtained using conventional headsets, which commonly consist of an earphone mounted in a circumaural hearing protector, is known to be insufficient for some applications at low frequencies. For this reason, "active" noise reduction (ANR), in which a corrective sound is generated electro-acoustically to reduce the combined sound field at a desired location, has been proposed for reducing the noise at the ears [1, 2].

The purpose of the present work is to explore the performance obtainable with a digital ANR system for such applications, based on the use of a circumaural headset and a floating-point digital signal processor (DSP). This paper reports our initial results.

2.0 Apparatus and Method

A digital ANR system has been constructed by adapting a commercial circumaural analogue ANR headset, the performance of which in its original condition has been reported elsewhere [3]. For the purposes of these experiments, the ear cup and cushion, earphone and attached microphone were retained from the commercial device. A block diagram of the system is shown in Figure 1, where the headset is represented by one ear cup shown in cross-section. The cushion was sealed by spring pressure characteristic of the headband force against the base plate of a cylindrical enclosure (shown in outline), which represents the surface of the head. The enclosure has been developed for measuring the performance of ear cups at frequencies from 10 to 1000 Hz, and sound pressures of up to 140 dB [4]. For the purposes of the present work, a 1/3 octave-band spectrum shaper (Bruel & Kjaer models 1612/S1A & SP) was used to equalize the loudspeaker output.

The sound field surrounding the headset was sensed by a miniature electret microphone attached to the exterior of the ear cup, which generates the "reference" signal, X. The microphone (Panasonic, type WM-063), together with its preamplifier, possess a flat frequency response from 50 Hz to 10 kHz (within 1 dB), and dynamic range of from 30 to 120 dB (re $2x10^{-5}$ Pa). Control of the sound pressure within the volume between the ear cup and the base plate of the enclosure is maintained by the miniature electret microphone attached to the earphone, which monitors the "error" signal. This microphone is used to sense the residual sound pressure after generation of the control sound field by the earphone, and was also used in these experiments to monitor the performance of the ANR system. The anti-aliasing and reconstruction filters were 8-pole, 6-zero elliptic low-pass filters with cut-off frequencies set to 5 kHz (Stanford Research Systems model SR640). A/D and D/A conversion employed 16 bit successive approximation converters integrated with the DSP board (Spectrum PC/C31). The complete DSP system is hosted in an IBM 486 PC.

The control system employs an adaptive feedforward structure, and uses a normalized filtered-X LMS algorithm [1]. Figure 2 shows a block diagram of the control algorithm, in which X, W, U, H, and E represent the reference input signal, the impulse response of the controller, the controller output, the impulse response of the error path (from U to E in Figure 1), and the error signal, respectively. W and H were implemented as 100 tap finite impulse response (FIR) digital filters, and H was identified off-line in the present work. The step size used to adapt the controller weights was normalized with an estimate of the input signal power, P. Updating of the controller weights is then effected by:

$$W_k = W_{k-1} + \bar{\mu}\, E(k)\, R_k$$

where $\bar{\mu}$ is the normalized step size (=μ/P), E(k) is the error signal at time k, and R_k is the filtered reference signal vector at time k

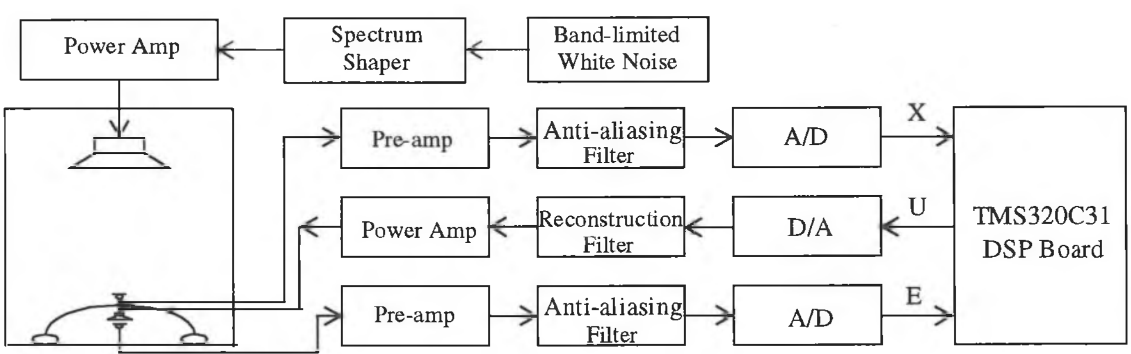

Fig. 1. An active noise control system for communication headsets.

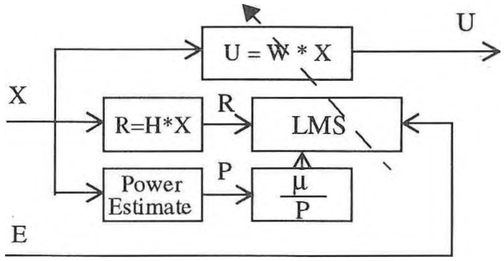

Fig. 2 Adaptive control algorithm

obtained from the convolution equation R = H * X. The control signal was then generated by filtering the reference signal, using the on-line adapted controller weights.

A Texas Instruments TMS320C31 DSP was used to implement the control system in real-time. The sampling frequency was chosen to be 10 kHz for the present work, and at this rate the DSP board functioned in real time without overload. The performance of the control system was recorded by a FFT analyzer (Stanford Research Systems model SR770), using the Blackman-Harris windowing function.

3.0 Results and Discussion

The performance of the ANR system was determined with the band-limited noise shown in Figure 3(a). This noise spectrum was recorded outside the ear cup by the reference microphone, and is considered "flat" within the limitations of the apparatus, from 80 to 750 Hz. A sound pressure was chosen outside the ear cup at which all electronic and electro-acoustic components of the system were operating linearly.

With this environmental noise spectrum outside the ear cup, the corresponding sound pressure in the volume enclosed by the ear cup is shown by the spectrum labelled "without control" in Figure 3(b). This spectrum was recorded by the error microphone, and reveals, by comparison with Figure 3(a), that the passive attenuation of the ear cup is approximately 10 dB at frequencies between 100 and 200 Hz, and increases to close to 30 dB at 800 Hz. This attenuation is in agreement with results previously reported for this ear cup [3], and also indicates the extent to which the secondary source within the ear cup will influence the sound field at the reference microphone.

The performance of the adaptive control system can be seen in Figure 3(b). After an initial period of adaptation, the stabilized sound pressure in the volume enclosed by the ear cup is shown by the dashdot line labelled "with control". It is evident from this spectrum that the control system produces significant noise reduction at all frequencies of the environmental noise, and has somewhat reduced the predominance of the components at frequencies from 100 to 200 Hz. Since both spectra in Figure 3(b) were recorded at the error microphone, the difference between them gives the attenuation introduced by the control system. This difference is in excess of 20 dB at frequencies from 80 to 200 Hz, and in excess of 15 dB at frequencies from 250 to 650 Hz.

The signal labelled "without control" also displays the initial

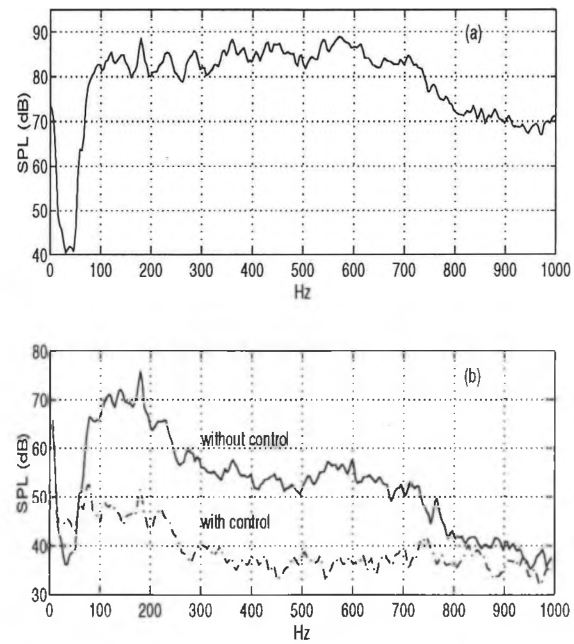

Fig. 3. (a) Spectrum of noise above headset; and
(b) Active noise reduction performance.

error spectrum that the control system experiences. This spectrum may be considered to be constructed from two band-limited noise signals of different amplitudes, with frequency ranges of from 80 to 200 Hz, and from 250 to 700 Hz. When viewed in this way, the results suggest that the current algorithm produces more attenuation when controlling the more intensive narrow-band noise. This inference suggests the use of parallel, frequency band-limited controllers to improve the performance of a digital ANR system for this application.

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