FIFTH INTERNATIONAL CONGRESS ON SOUND AND VIBRATION
DECEMBER 15-18, 1997
ADELAIDE, SOUTH AUSTRALIA

A New Active Headset For a Helicopter Application

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Abstract

In helicopters, the low frequency noise generated by the rotors and engines often masks and jeopardizes safe communication. Additionally, pilots are likely to suffer from hearing damages due to the higher sound levels in the headset produced when compensating for the noise by increased speaker levels. A feasible approach is to reduce the low frequency noise using active techniques, thereby enabling lower speaker levels.

In many Active Noise Control (ANC) applications the primary noise field is either periodic or broadband which simplifies the choice of algorithm. In our application, noise up to 100 Hz is dominated by tones and in the range from 100 Hz to 400 Hz the noise characteristics is more broadband. In order to achieve an efficient attenuation of the primary noise, a combination of a digital feedforward controller and an analog feedback controller is employed. The feedforward controller is tachometer based and reduces the tonal components, while the feedback controller attenuates the more broadband noise. In this paper, a combination of these two techniques is evaluated on real data.

1 Introduction

For helicopter pilots it is important during flight to hear radio communication correctly. The low frequency noise generated by the engines and rotors (main and tail rotor) masks and corrupts the communication [1],[2]. In order to increase the speech intelligibility the noise level inside the ear cups have to be reduced. Since the noise has a low frequency characteristics, it is not suitable to reduce the noise by employing passive techniques. A more feasible approach is to reduce the noise by employing Active Noise Control (ANC) technique.

This paper treats the concept of a hybrid ANC headset that combines both feedforward and feedback ANC techniques [3]. The adaptive feedforward controller is based on a digital system, while the feedback system is based on an analog system. The principle of the hybrid headset is depicted in figure 1. This type of ANC headset is used in order to improve the noise attenuation. The feedback controller reduces broadband noise, while the feedforward controller reduces narrowband noise (harmonics of the main and tail rotor). Typically, noise up to 100 Hz is dominated by tonal components while in the range from 100 Hz to 400 Hz, the noise characteristics is more broadband.

The feedback controller is based on a commercial analog headset. Pure analog feedback technique will not be discussed in the paper. This paper is focused on the adaptive algorithm used in the digital feedforward controller as well as the performance of the hybrid headset.

The feedforward controller utilizes a tachometer signal related to the main rotor to generate reference signals to the controller. Noise components that correlate with the reference signals will be suppressed. The references are fed through the feedforward controller and the output of the controller is summed with the output of the feedback controller before driving the loudspeaker, which generates a secondary sound field that is 180° out of phase with the primary sound field. An error microphone inside the ear cup measuring the residual noise is used to adjust the adaptive feedforward controller.

The principle of the feedback controller is: The output signal of the error microphone is fed back through an analog amplifier with magnitude and phase response designed to produce an output that results in noise attenuation at the error microphone.

The adaptive algorithm employed in the feedforward controller is based on the complex filtered–X Least–Mean–Square (LMS) algorithm, [4],[5]. The proposed complex algorithm is advantageous in narrowband applications due to high convergence rate and low numerical complexity. The fundamental reasons are the orthogonality of the quadrature components (or Hilbert pairs) constituting the complex reference signals, and the simplicity of complex representation. In fact, the complex algorithm requires a minimum of adaptive and acoustic path parameters as compared to a straight forward time-domain approach with ordinary FIR filters.

2 The Feedforward Controller

The noise up to 100 Hz inside the helicopter consists essentially of narrowband harmonic components related to the rotational frequencies of the main and tail rotor. It is assumed that there is a periodic tachometer signal available which is correlated to the noise harmonics. For this reason a model with pure sinusoidal reference signals and complex notation will be used below.

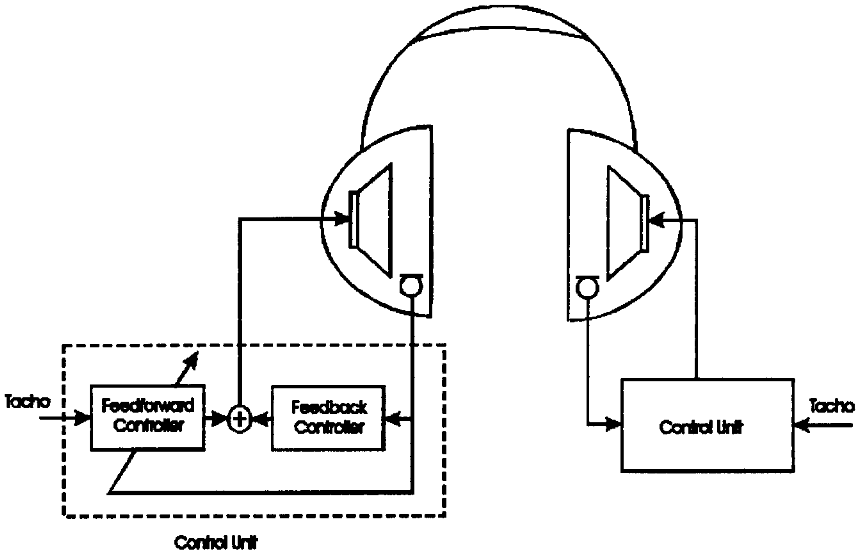

Figure 1: The principle of hybrid ANC headset based on feedforward and feedback control.

The adaptive feedforward controller [8] is based on the complex LMS–algorithm [6],[7]. Consider the Single Input Single Output (SISO) ANC system configuration [8], depicted in figure 2.

The controller is described for a general situation with H harmonics. Each harmonic is individually controlled. Let $s(n)$, $x_h(n)$, w_h and f_h denote the tachometer signal, the complex scalar reference signal, the complex scalar loudspeaker weight and the complex acoustic path from the loudspeaker to the error microphone respectively for the hth harmonic. The set of complex reference signals $x_h(n)$ is generated from the tachometer signal $s(n)$, for example by using an FFT–filter bank or using lookup table technique.

The real error microphone signal $e(n)$, is given by

$$e(n) = d(n) + \sum_{h=1}^{H} \Re\left\{f_h x_h(n) w_h\right\} \tag{1}$$

where $d(n)$ is a real signal representing the primary sound field at the error microphone (at the discrete time index n). Here $\Re\{\cdot\}$ denotes the real part operation.

The objective function to be minimized is given by

$$\xi_n = e^*(n)e(n) \tag{2}$$

where $(\cdot)^*$ denotes complex conjugation. The derivative of $\xi_n = e^*(n)e(n)$ with respect to w_h is given by

$$\frac{\partial \xi_n}{\partial w_h^*} = x_h^*(n) f_h^* e(n). \tag{3}$$

The complex gradient in (3) is used to define the updating scheme of the adaptive algorithm, given by

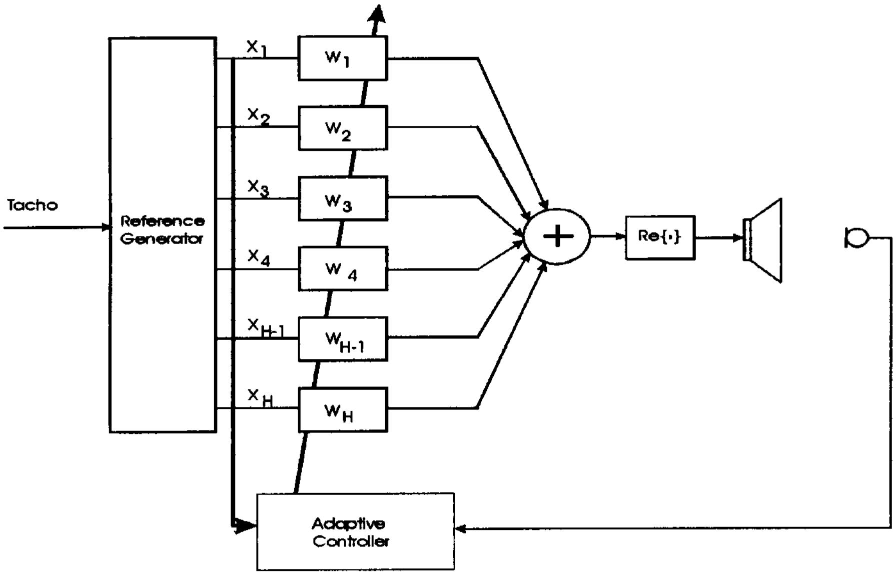

Figure 2: Single Input, Single Output (SISO) system for active noise control.

$$w_h(n+1) = w_h(n) - 2\mu_h x_h^*(n) f_h^* e(n). \tag{4}$$

The convergence factor μ_h is given by

$$\mu_h = \frac{\mu_0}{\rho_h |f_h|^2} \tag{5}$$

where μ_0 is a positive normalized convergence factor and $\rho_h = E\left\{|x_h(n)|^2\right\}$ (the power of the signal x_h). The power of the reference signal x_h is estimated by using an exponential moving window technique as follows

$$\hat{\rho}_h(n) = (1-\beta)\hat{\rho}_h(n-1) + \beta |x_h(n)|^2 \tag{6}$$

where β is a weighting factor.

In a practical application, the acoustic path f_h is unknown and must be estimated. Therefore, f_h should be exchanged for the corresponding estimate $\hat{f}_h$ in (3),(4) and (5).

3 Evaluation

The evaluation has been done on data recorded in a AS332 "Super Puma MKII helicopter during flight. The two engines in the helicopter always run with the same rpm. Hence, the sound field is quite stationary. The noise inside the cabin contains strong tonal components originating from the main and tail rotors and in order to achieve an efficient noise reduction inside the ear cups it is necessary to reduce the BPFs and their related harmonics. The feedforward controller presented in this paper was set

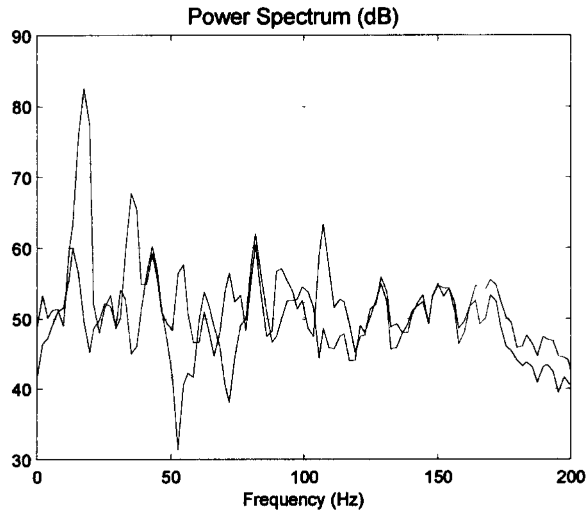

Figure 3: Sound pressure level of the primary and reduced noise. Upper curve: Primary noise inside the helicopter. Lower curve: Reduced noise inside the ear cups after the feedforward controller is switched on.

up to cancel the BPF to 5×BPF for the main rotor and the BPF for the tail rotor, respectively.

Figure 3 shows the performance of the feedfoward controller only. The frequency range is 0 to 200 Hz. The following attenuation of the dominating tones was obtained :

Frequency Component	Frequency	Attenuation [dB]
BPF, Main rotor	17.7	23
2xBPF, Main rotor	35.3	22
3xBPF, Main rotor	53.0	22
4xBPF, Main rotor	70.7	17
5xBPF, Main rotor	88.3	8
BPF, Tail rotor	106.7	15

The BPF for the main rotor is 17.7 Hz and is outside the audible frequency range. The attenuation of the tones is satisfying but the audible result is limited. Note also that the 6xBPF for the main rotor is the same as BPF for the tail rotor. Which makes it more easy when generating the reference signals.

In figure 4 the performance of the feedback controller combined with the passive damping of the ear cups is shown. The analog system is a commercial headset fitted into a headset from Hellberg Safety AB, with closed ear cups. The analog system only affects the spectrum approximately up to 400 Hz. Hence, the frequency range 0-400 Hz is only presented. The controller achieves a broadband noise attenuation of approximately 20 dB in the given frequency range. Note that the components are still present.

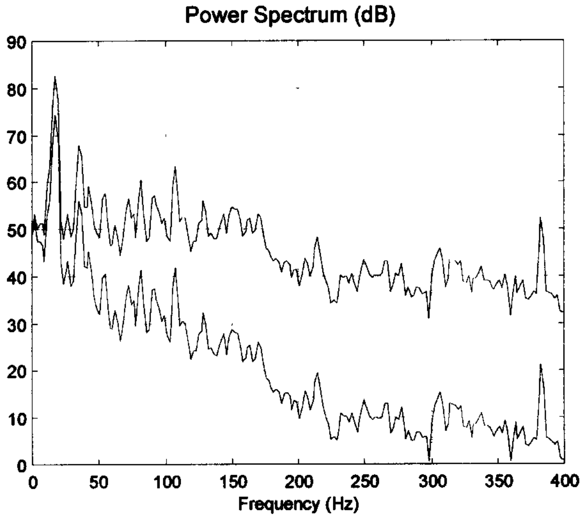

Figure 4: Sound pressure level of the primary and reduced noise. Upper curve: Primary noise inside the helicopter. Lower curve: Reduced noise inside the ear cups after the analog feedback controller is switched on.

Since the passive damping of the ear cups and the analog controller affects the broadband noise reduction, it is interesting to investigate how the broadband reduction will be affected when the analog controller is switched on and off. The difference between the passive damping versus the passive damping together with the analog controller is depicted in figure 5 .When the analog controller is on, a more efficient broadband reduction is achieved. This figure also shows the noise attenuation when also a narrowband controller is used. The feedfoward controller does not affect the broadband attenuation of the noise. This controller only reduces the tones.

Finally, in figure 6 the result of the hybrid headset is shown. A combination of feedforward and feedback control results in significant damping of both the tones and the broadband noise.

4 Summary and Conclusions

There are substantial noise levels in helicopters, especially at low frequency. These levels are normally not harmful to the ear. However, the low frequency content masks the speech. For this reason, pilots tend to set the intercom system to maximum sound level, producing potentially damaging sound levels for the human ear. The sound levels inside the ear canal have been measured to almost 100dB(A) when the intercom system is in use. Such high sound levels expose the ear to fatigue and hearing loss. It is therefore important to lower the background noise and a hybrid headset is proposed to solve the problem. The headset consists of a digital feedforward controller based on a complex LMS-algorithm and an analog feedback controller. This combination results in efficient noise reduction of approximately 20 dB broadband and 20 dB of the tonal

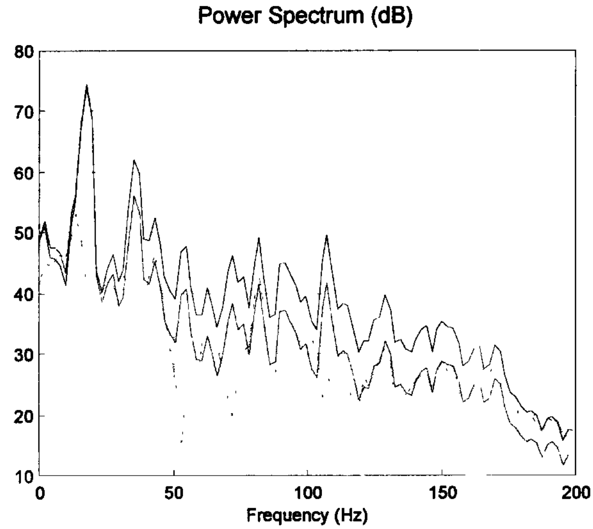

Figure 5: Sound pressure level of the noise inside the ear cups. Upper solid line: No controllers are on, only the passive damping. Dotted line: Passive damping and the analog controller. Lower solid line: Hybrid headset.

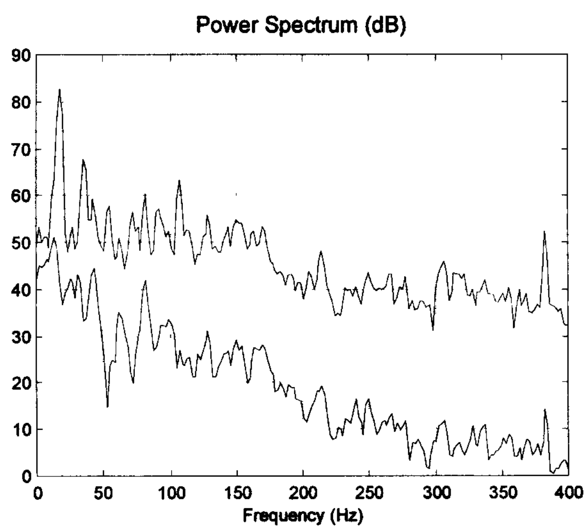

Figure 6: Sound pressure level of the primary and reduced noise. Upper curve: Primary noise inside the helicopter. Lower curve: Reduced noise inside the ear cups after the hybrid headset is switched on.

components.

5 Acknowledgments

The authors wish to express their gratitude towards Captain Arne Sjölund and his crew at the F17 air force base in Kallinge, Sweden for all the support during the measurements of the sound pressure and tacho signals.

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