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REAL-TIME REDUCTION OF POWER LINE INTERFERENCE IN MULTI-CHANNEL SURFACE EMG

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INTRODUCTION

Electrophysiological signals are generally noisy because of their low amplitudes and the body's susceptibility to power line interference. Hardware techniques (active electrodes, DRL circuit, virtual ground circuit, electrode-skin impedance equalization, and guarding systems) have been proposed to reduce power line interference. Residual power line interference superimposed to the acquired data can be removed by digital signal processing techniques. Power line interference may vary slowly in frequency within 0.2-1.0%. A new digital processing method to remove power line interference is proposed, which is a multi-channel modified version of the method presented in [2].

METHODS

Signal Model

The recorded data vector $\vec{x}(n)$ is the sum of the multi-channel EMG signal vector $\vec{s}(n)$ and a power line interference vector $\vec{i}(n)$ whose waveshape is assumed to be the same in all channels, referred to as $I(n)$, up to an unknown amplitude modulation weighting factor vector $\vec{a}(n)$

$$\vec{x}(n)=\vec{s}(n)+\vec{i}(n)=\vec{s}(n)+\vec{a}(n)\cdot I(n)$$

The algorithm

Widrow Adaptive Noise Canceller (ANC): given a reference sinusoidal signal, the weights $\vec{W}(n)$ of a sine and a cosine function are estimated optimally (in the Least Mean Square sense) to match the amplitude and the phase of the interference. The reference signal was obtained using a Phase Locked Loop (PLL). Reference signals were generated for each harmonic by multiplication of the output of the PLL (which follows only the fundamental harmonic) by the harmonic number and duplicating the Widrow method. The estimated interference reference signals were then subtracted from the recorded data.

The method was then extended to remove the interference from more channels, exploiting the information recorded by the multi-channel recording system. The common mode was enhanced by averaging across all channels, which improves the estimation of the interference.

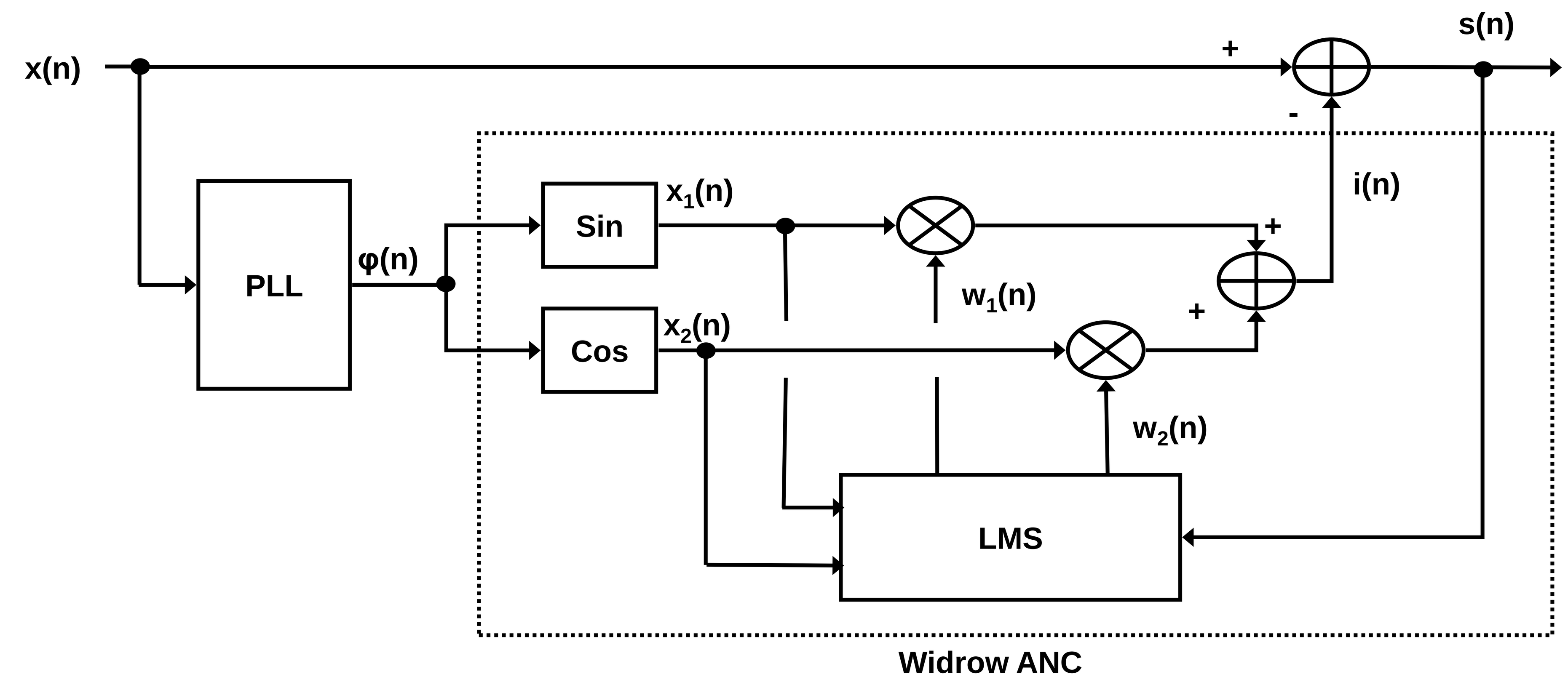

Figure 1. Block diagram of the single channel, single harmonic method. The method is extended to remove all the harmonics of interest of power line interference from more channels.

Test of the method

The method was tested by adding simulated EMG signals [1] to both simulated and experimental interference (the latter acquired from a subject during rest – no EMG activity). The performance of the method was described in terms of the Signal to Interference Ratio (SIR - expressed in dB) obtained averaging across the N channels:

$$SIR=\frac{1}{N}\sum_{k=1}^{N}10\log\frac{\sum_n s_k^2(n)}{\sum_n i_k^2(n)}$$

where the energies of the signal $\sum_n s_k^2(n)$ and of the interference $\sum_n i_k^2(n)$ of the k^{th} channel are evaluated summing over the simulated epoch (duration 1 s).

The performance of the method depended on the considered power line interference. The best performance was obtained when the amplitude and the frequency of the interference did not vary in time. Time variations of amplitude $\vec{a}(n)$ and frequency $f_i(n)$ of the interference were introduced in order to assess the conditions under which the method improves the SIR. Eight harmonics of the power line interference were considered. Harmonics have different amplitudes, which depend on the loading of power line. A weight inversely related to the order of the harmonic *h* was assigned. Thus, in summary, the power line interference present in an arbitrary recorded channel *k* was described by the following equation:

$$i_k(n)=a(n)\sum_{h=1}^{H}G(h)\sin\left(2\pi h f_i(n)+\phi(h)\right) \quad \text{where} \quad G(h)=1/h$$

RESULTS

Effect of varying the amplitude of the simulated interference on simulated signal.

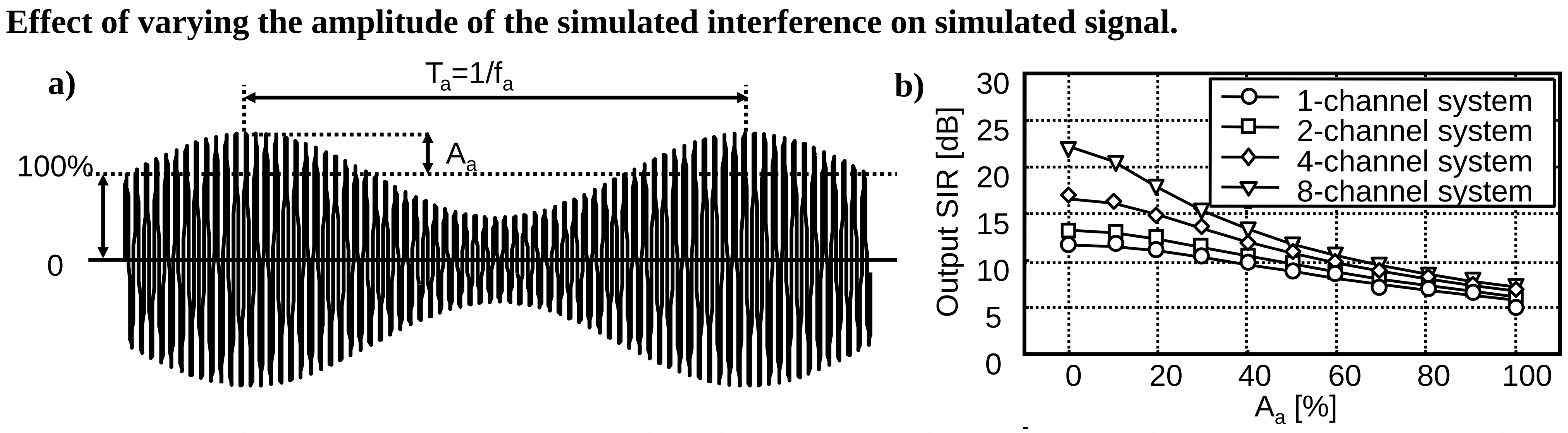

Figure 2. a) Variables that are changed in this set of simulations. The interference was modeled as having a varying amplitude A_a, and a fixed frequency f_a. b) Effect of changing A_a when f_a is fixed at 0.5 Hz. Input SIR = 10 dB.

Effect of varying the shape of the interference in different channels of simulated signals.

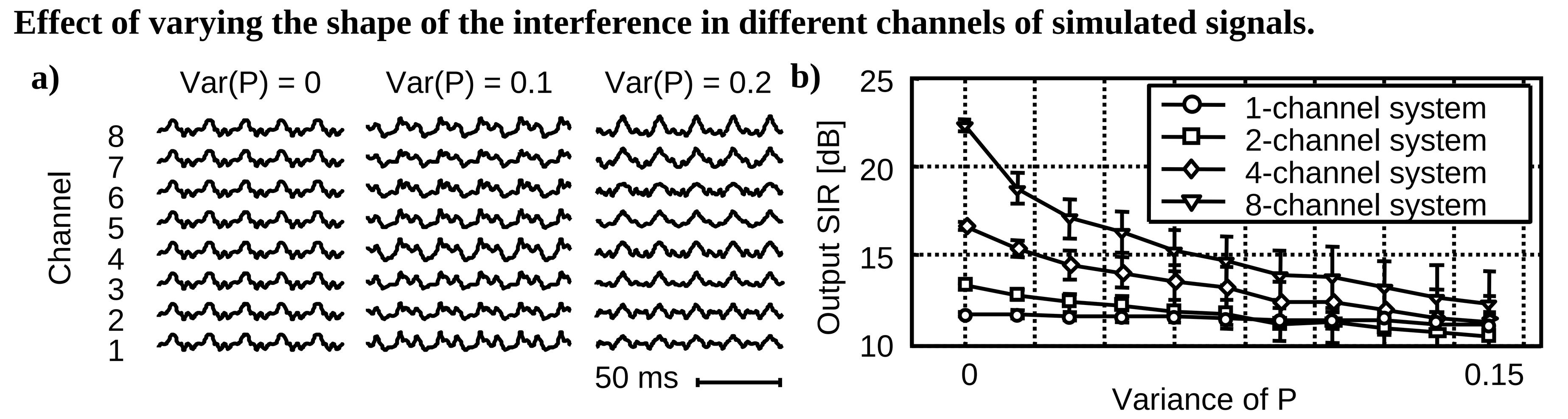

Figure 4. a) Power line interference in different channels when the amplitude of the h^{th} harmonic is $G_P(h)=\frac{1+P}{h}$ where P is a Gaussian random process with zero mean and different variance in different simulations.
b) Output SIR as a function of the variance of the process P (average across 10 realizations). Input SIR = 10 dB.

Effect of varying the frequency of the simulated interference on simulated signal.

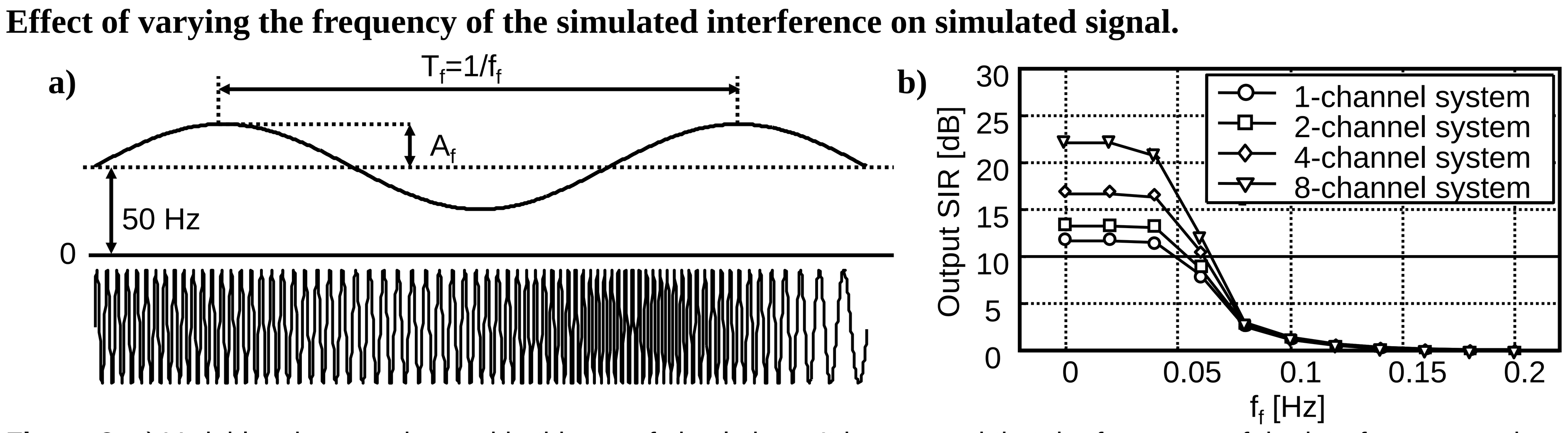

Figure 3. a) Variables that are changed in this set of simulations. It is assumed that the frequency of the interference can be modeled as having a fixed amplitude A_f, and a varying frequency f_f . b) Effect of changing f_f when A_f is fixed at 0.5 Hz. Input SIR = 10 dB.

Effect of varying the inter-electrode distance (IED) on simulated signal.

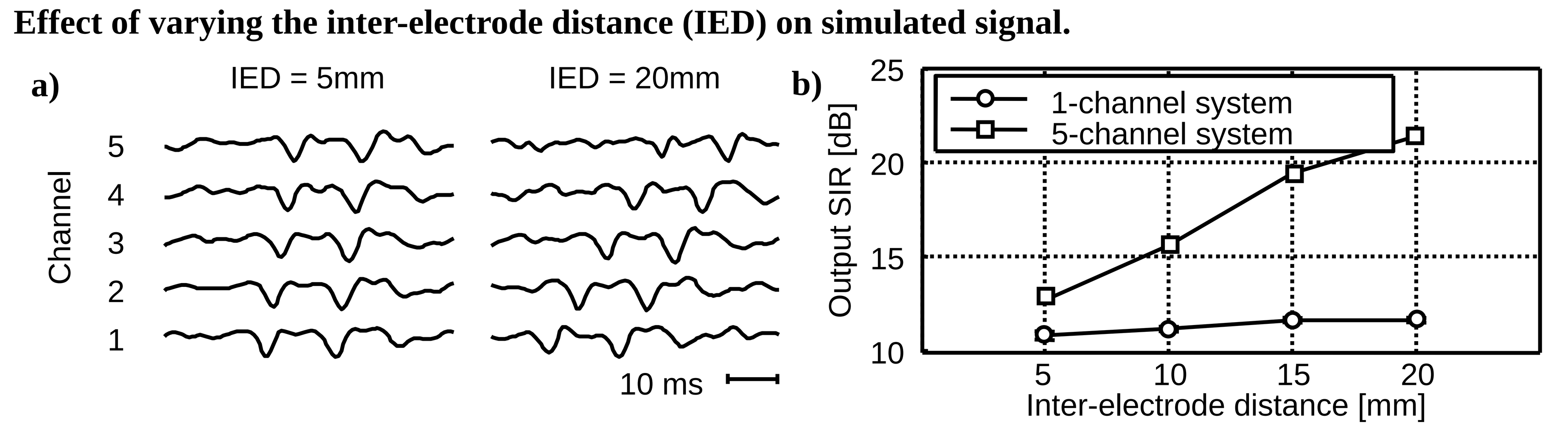

Figure 5. a) Example of simulated signals with different IED (5 mm and 20 mm). The simulated interference was the same in both cases. b) Effect of changing IED. By increasing IED, the surface EMG signals have a lower correlation and the extraction of the common mode by averaging the signals is more efficient). Input SIR = 10 dB.

Effect of varying input SIR when using simulated data added either to a simulated or to an experimental interference signal.

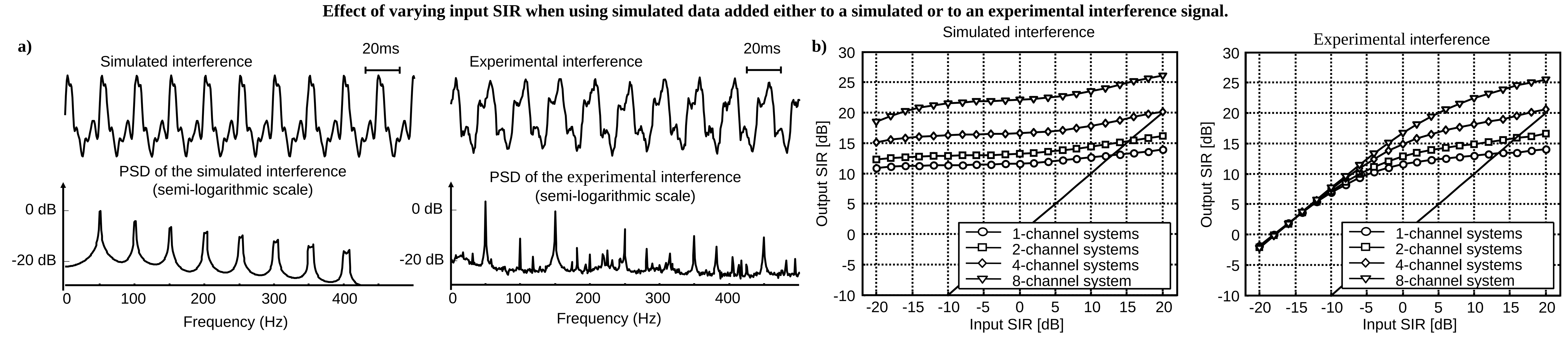

Figure 6. a) Simulated and experimental power line interference signal and PSD estimates (by the Welch averaging method) in a semi-logarithmic plot. b) Application of the method to signals with different input SIR obtained adding simulated or experimental interference to simulated EMG signals.

CONCLUSIONS

A new method to remove power line interference was applied to surface EMG signals. A multi-channel adaptive filter technique was used, with reference signal obtained by averaging across channels and tracking the interference by a PLL. Results showed that the method improved output SIR with respect to input SIR both in the case of simulated and experimental interference. The performance improved by increasing the number of channels.

REFERENCES

[1] Farina D and Merletti R, "A novel approach for precise simulation of the EMG signal detected by surface electrodes", IEEE Trans Biomed Eng, vol. 48, pp. 637-646, 2001.
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