Estimation of monopolar signals from spincter muscles and removal of common mode interference

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ESTIMATION OF MONOPOLAR EMG SIGNALS FROM SPHINCTER MUSCLES

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1. INTRODUCTION

Surface electromyogram (EMG) is usually recorded by means of spatial filters with vanishing sum of weights. More information could be extracted from monopolar signals measured with respect to a reference electrode away from the muscle. Under some assumptions, surface EMG detected along a line parallel to the fiber path has zero mean value in space at any time. This property is a constraint which can be used to estimate monopolar signals from single differential (SD) EMG signals and is satisfied in the case of a circumferential electrode array surrounded by a circular muscle.

2. METHODS

The problem of estimating monopolar signals $\vec{m}(t)$ from SD $\vec{s}(t)$ is not well posed. Indeed, there are infinite solutions, as an arbitrary function of time $f(t)$ can be added to the monopolar signals without affecting the SD signals $s_i(t) = m_i(t) + f(t) - (m_{i+1}(t) + f(t)) = m_i(t) - m_{i+1}(t)$

SD signals from an array of N electrodes can be expressed in terms of monopolar signals as follows

$$\vec{s}(t) = \underline{\underline{A}}\,\vec{m}(t) \qquad \underline{\underline{A}} = \begin{pmatrix} 1 & -1 & 0 & \cdots & 0 \\ 0 & 1 & -1 & \vdots & \vdots \\ \vdots & \cdots & \ddots & \ddots & 0 \\ 0 & \cdots & 0 & 1 & -1 \end{pmatrix} \quad \begin{matrix} N-1 \ \textit{rows} \\ \\ \\ \\ N \ \textit{columns} \end{matrix}$$

Matrix $\underline{\underline{A}}$ cannot be inverted as it has a vanishing eigenvalue, associated to an eigenvector with constant entries.

Nevertheless, the pseudoinverse of matrix $\underline{\underline{A}}$ can be evaluated and monopolar signals can be estimated as $\vec{m}_{est}(t) = \underline{\underline{A}}^{\#}\vec{s}(t)$

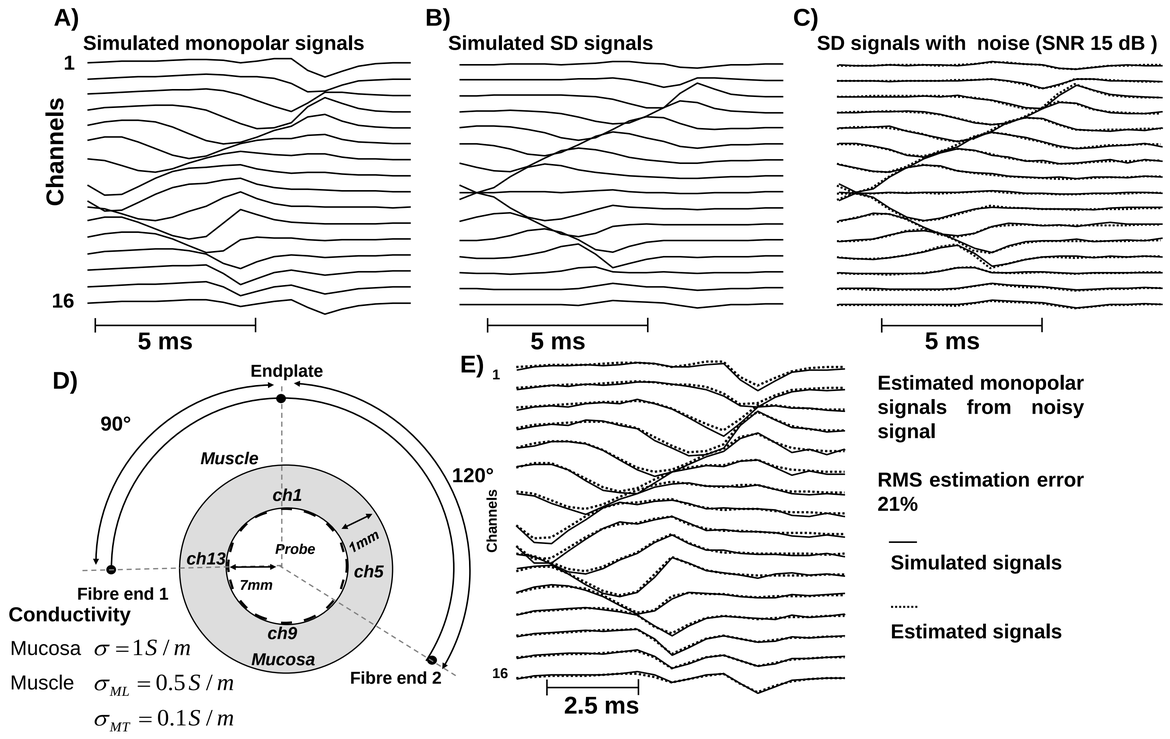


Figure 1 A) Example of simulation of monopolar SFAP, using a model of sphincter. B) SD signals obtained from the monopolar signals. C) SD signals with 15 dB white noise. D) Estimate of monopolar signals from perturbed SD signals.

Under the assumption that the volume conductor is space invariant, the monopolar surface EMG detected along a curve parallel to the fiber path has zero mean value in space at any time.

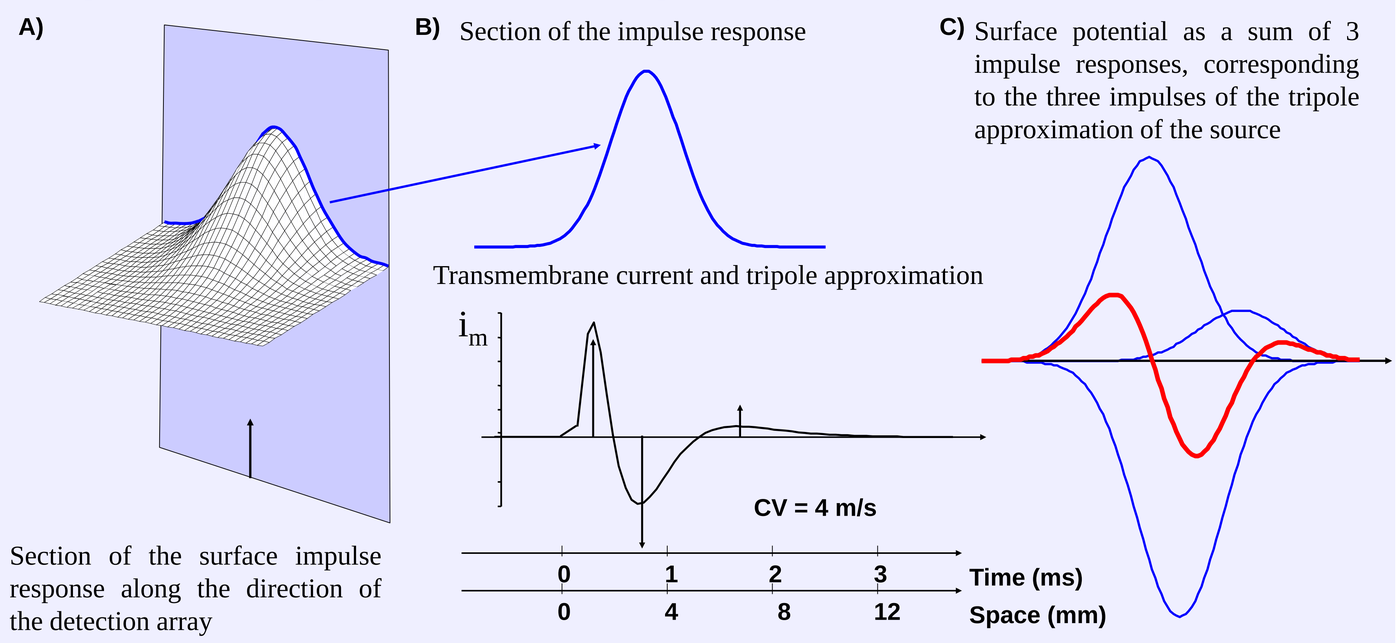


Figure 2 A) Sketchy representation of an impulse response. B) Section of the impulse response at the location of the detection system in the direction of muscle fibres and transmembrane current (source of the volume conductor problem). C) Surface potential along the direction of the muscle fibres expressed as a convolution of the source (tripole approximation) with the impulse response.

3. RESULTS

Application to simulated SFAPs

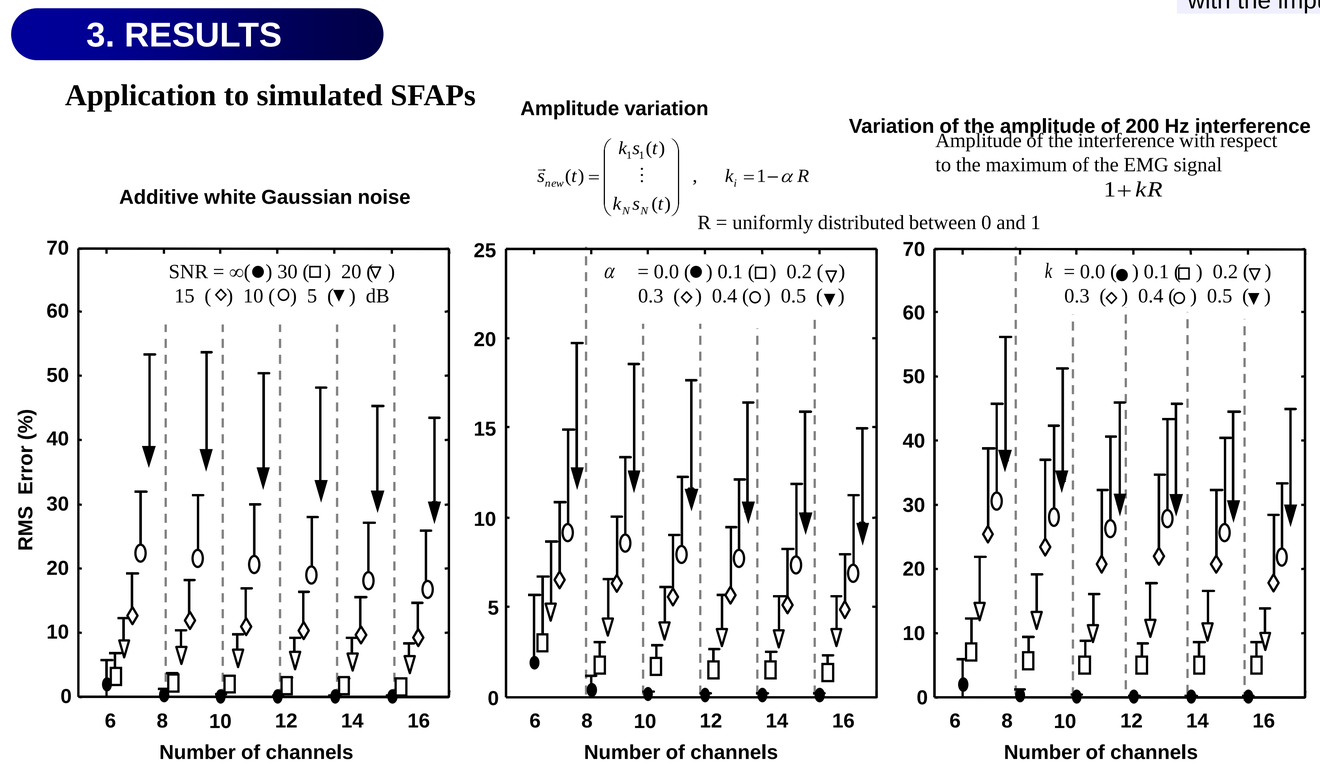


Figure 3 Performance of the method. Mean and STD of the RMS error in estimating monopolar from SD SFAP corresponding to 88 positions of simulated fibers (depth between 2 and 8 mm within the muscle with 1 mm step, distance of the fibres from the detection electrodes in the axial direction between 0 and 10 mm with 1 mm step)

Application to simulated noise free MUAPs and interference signals

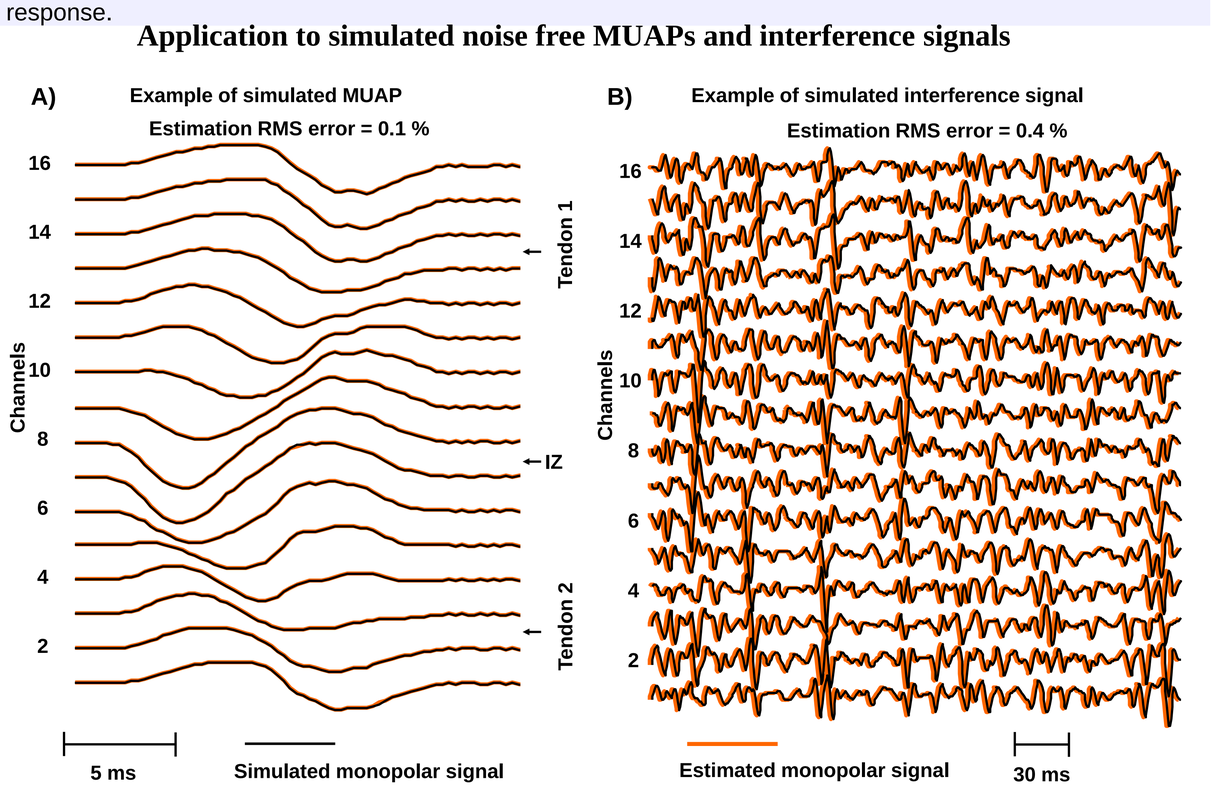


Figure 4 A) Application of the method to a MUAP (MU constituted by 154 fibers) and B) to an interference signal (60 MUs, force level 40% MVC). SD signals were obtained from the simulated monopolar signals, and then monopolar signals were reconstructed.

Application to signals simulated by a planar model

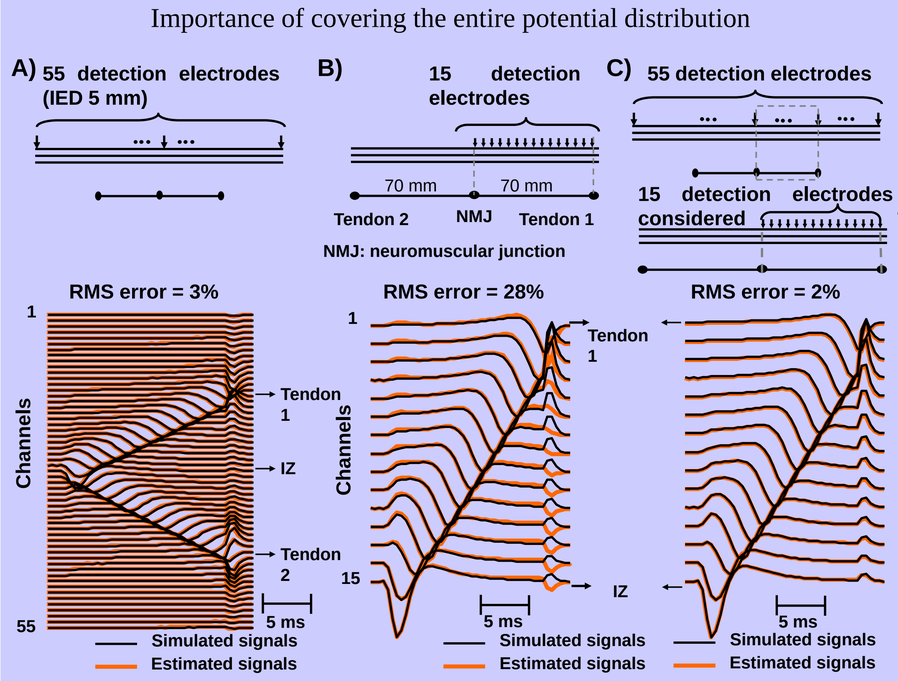


Figure 5 A) Simulated and reconstructed monopolar signals from 55 channels detection, with the array covering the entire potential distribution B) Case of 15 channels detection, with the array between the innervation zone and one tendon. C) 15 channels in the same position as in B), but considering for the estimation all the 55 channels detection as in A).

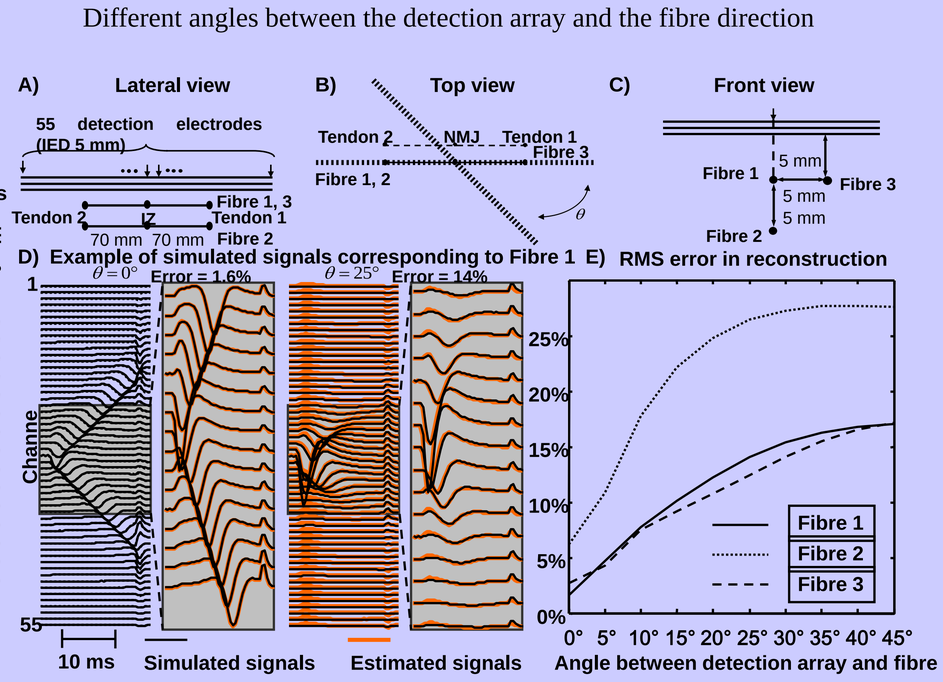


Figure 6 Lateral A), top B) and transversal C) views of the simulated configuration. D) Representative example of simulated monopolar signals and their reconstruction, in the case of 0° and 25° of misalignment between detection array and muscle fibres. E) Reconstruction error for each of the three simulated fibres at misalignment angles in the range 0° to 45°.

Considerations on the estimation error

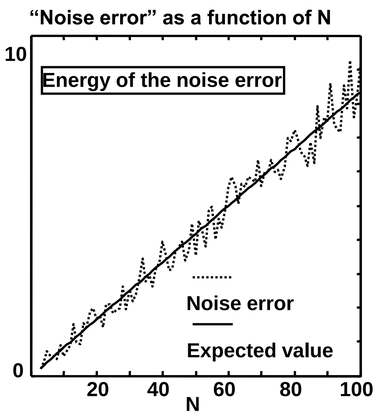
The estimation error is the sum of the "approximation error" due to sampling and the "noise error" due to additive noise (supposed to be Gaussian with zero mean and standard deviation σ).

The "approximation error" is the common mode present in the vector of sampled monopolar signal and reduces with increasing number of channels N

Energy of errors in the estimation of monopolar signals from N SD signals with additive Gaussian noise with constant energy

Mean noise error:

$$\sum_{j=1}^{N} A_{ij}^{\#2}\,\sigma^2 \cong \frac{N}{12}\sigma^2$$



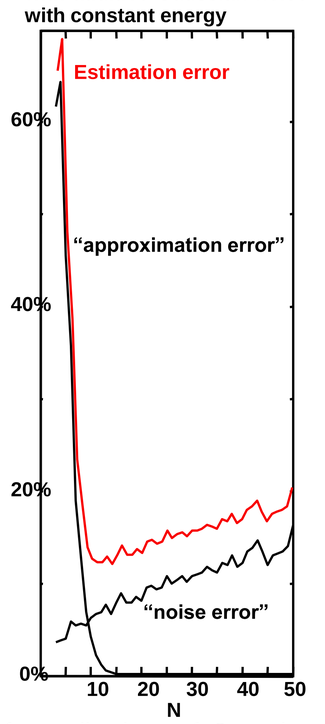


Figure 7 A) Square "noise error" for realisations of Gaussian noise (mean 0, STD 1) compared to the theoretical expected value as a function of the number of channels N. B) RMS "approximation error", "noise error" and estimation error normalised with respect to the square root of the energy of the monopolar signals of a representative SFAP (fibre located under the detection array, 1 mm deep in the muscle).

4. CONCLUSIONS

Under the hypothesis of space invariance of the volume conductor, monopolar signals detected along the direction of the muscle fibres with an array covering the entire spatial support of the potential distribution have vanishing spatial mean at any time. This provides a constraint for estimating monopolar from SD signals from sphincter muscles.

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