Extended Signal Space Separation method for improved interference suppression

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Introduction

- Signal space separation (SSS) is an efficient method for suppressing external interference in multichannel magnetoencephalography (MEG) data. [1]
- SSS is a general approach based on the physics of magnetic fields.
- The shielding factor (SF) against external interference provided by SSS is limited by the accuracy of sensor calibration and geometry.
- The current fine-calibration adjustment yields a calibration accuracy of ~0.1%, which typically corresponds to SSS-based SF of ~150. [2]
- More efficient suppression may be needed, e.g., in a light-weight magnetically shielded room (MSR) in magnetically noisy hospital environment.

Materials and Methods

Extended Signal Space Separation (eSSS)*

- We extended conventional SSS by adding statistical aspects of the data to the physical SSS modelling:
  1. Most dominant principal components, $\mathbf{PCA}_{out}$, are estimated from empty MSR recording with interference fields only.
  2. Basic SSS basis $\mathbf{S} = [\mathbf{S}_{in}\ \mathbf{S}_{out}]$ is extended with $\mathbf{PCA}_{out}$ such that $\mathbf{S}_{ext} = [\mathbf{S}_{in}\ \mathbf{S}_{out,\,ext}]$ and the orthogonalized extended external space $\mathbf{S}_{out,\,ext} = \mathrm{orth}([\mathbf{S}_{out}\ \mathbf{PCA}_{out}])$.
- The statistical extension makes the basis less prone to calibration inaccuracies while retaining the generality of the conventional SSS against dynamically changing interference patterns.
- $\mathbf{S}_{ext}$ can be used in SSS processing in typical way to suppress the external interference by reconstructing the internal subspace of the data.

Simulations

- A magnetic dipole was moved along the negative z-axis from 0 to 3 m in the MEG device coordinates, and the associated signal detected by the 306-channel Elekta Neuromag® MEG sensor array was calculated.
- Empty-MSR data for PCA estimation were simulated using real external field multipole moment time courses and amplitudes from measured data together with known fine-calibration.

Data collection

- Moving coil inside MSR: Real MEG measurements from empty MSR and with moving coil inside MSR from 0.1 to 1.5 m on the z-axis were performed using Elekta Neuromag® (Elekta Oy, Helsinki, Finland) system (sampling at 600 Hz, pass-band 0.1–200 Hz).
- Strong external interference: Phantom dipole and empty MSR data sets were measured at factory, in an environment with large external interference, using Elekta Neuromag® TRIUX system (sampling at 1 kHz, pass-band 0.1–330 Hz).

Data processing

- Basic SSS processing: with and without fine-calibration information, SSS expansion orders $L_{in} = 8$, $L_{out} = 3$.
- Extended SSS processing: The PCA vectors were defined from the empty-MSR recordings, together for gradiometers and magnetometers, and the number of vectors was 3 in the simulation and 8 with the real data.
- The shielding factor of the processing was estimated as the ratio of magnetometer norms in raw and processed signals.

Results

Simulation

- SSS gave expected SF, limited by the calibration inaccuracies, saturating to SF~20 for the non-calibrated device and ~150 with fine-calibration.
- eSSS increases the SF due to its independence of calibration accuracy given by the statistical approach, reaching SF of ~1500 (Fig. 1).

Moving coil inside the MSR

- The SF of eSSS increased on average by a factor of 1.5 compared to conventional SSS (Fig. 2).

* Not commercially available from Elekta Oy, patent number WO2012004458

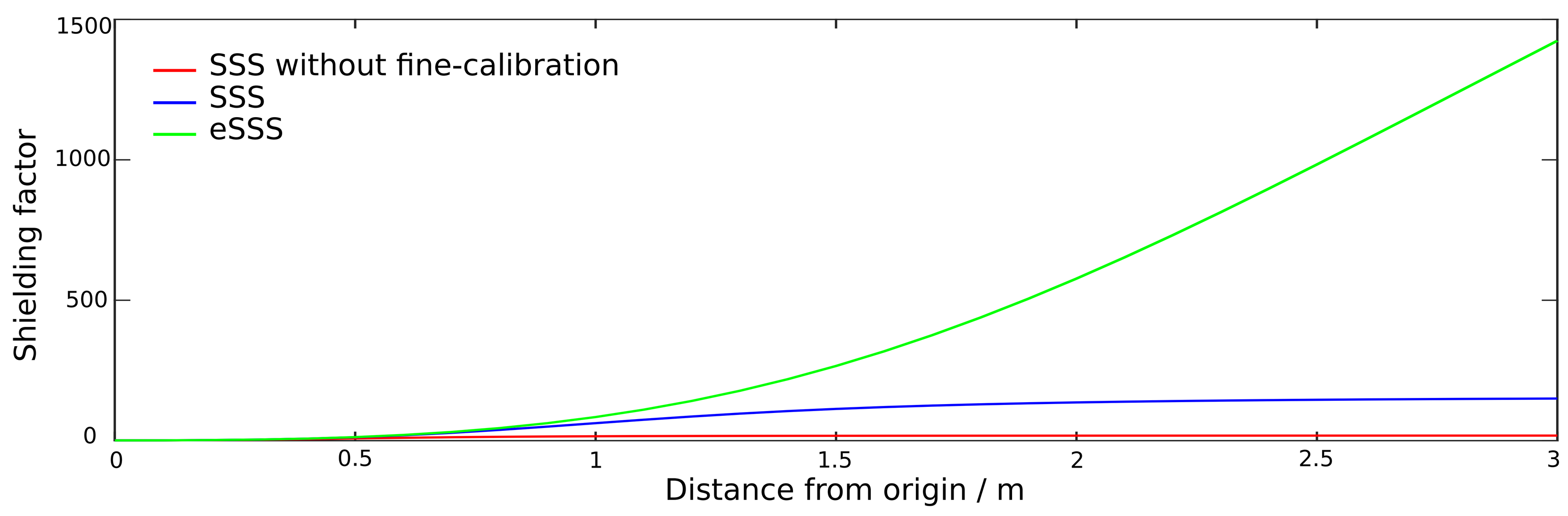

Figure 1. Simulated shielding factor as a function of distance of the source from the MEG device origin

- Lower performance than in simulations is expected to originate from the coil-related reflection of magnetic fields from the walls and floor of the MSR.

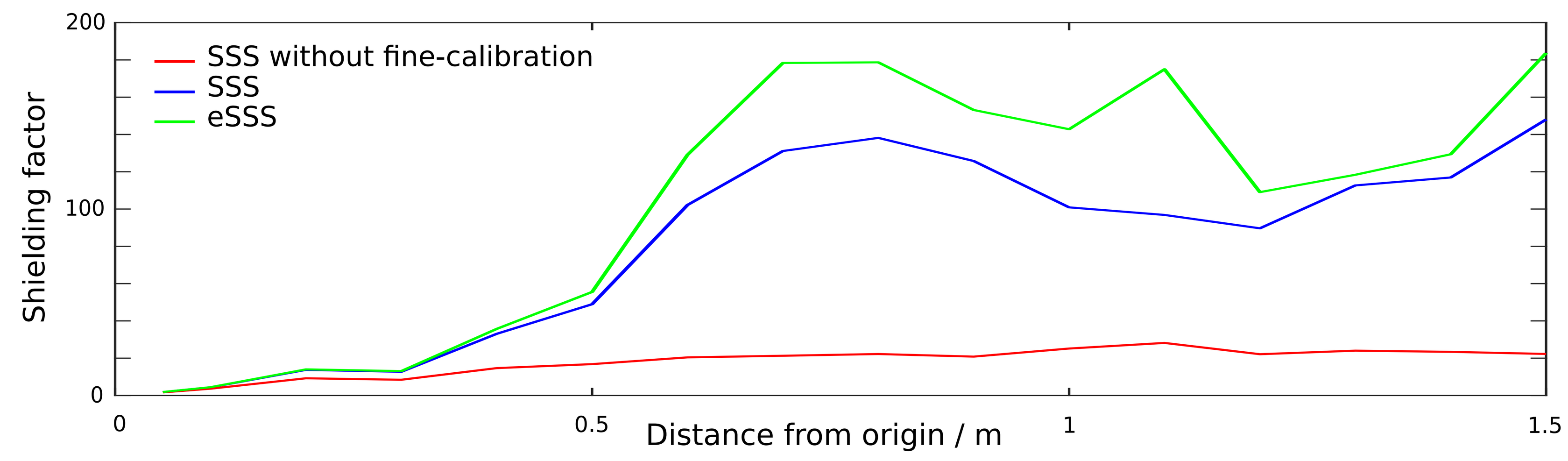

Figure 2. Measured shielding factor inside the MSR as a function of distance of the source from MEG device origin

External interference and dipole signal

- Interference fields emanating from sources outside of the MSR do not pose similar reflection field problems than interference generated inside the MSR.
- The increase in SF with eSSS can thus be dramatic compared to SSS. In the sample data set, the SF of eSSS reaches 3000 whereas the SF of SSS remains at 300 (Fig. 3).
- The amplitude of the dipole signal in the data is not reduced, and the dipole localization is not biased.

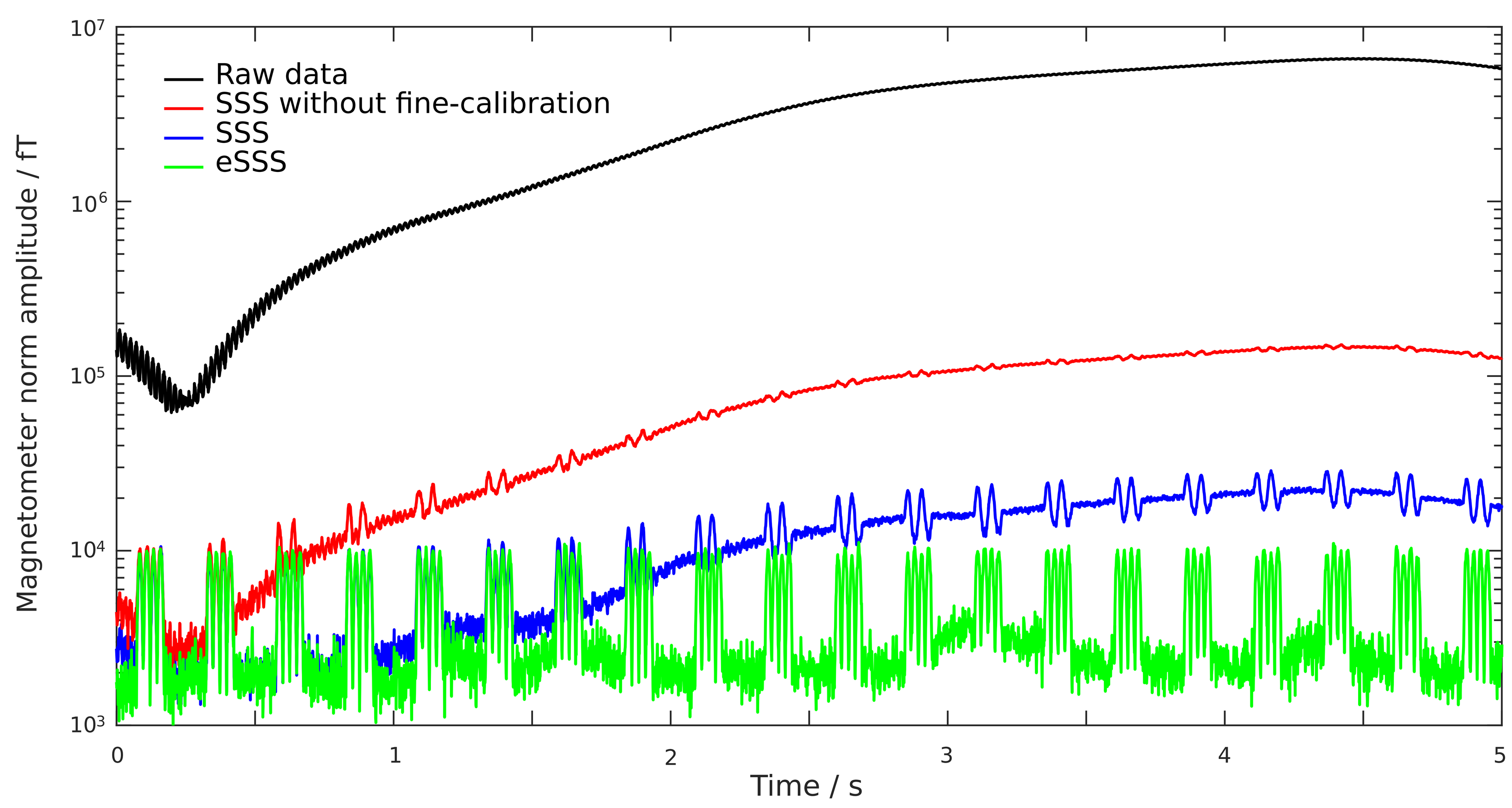

Figure 3. External interference fields suppressed using SSS and eSSS in data containing phantom dipole signals

Conclusion

- Due to the embedded statistical information, the eSSS method is more robust against calibration and geometry inaccuracies than the conventional SSS.
- eSSS is a general-purpose interference suppression method as it models external interference primarily with SSS, which, unlike e.g. Signal Space Projection (SSP) [3], adapts to changing interference patterns due to its physical model.
- Suppression of interference generated inside the MSR is slighly better than that in conventional SSS.
- Suppression of interference originating from sources outside the MSR can exceed factor of 1000, clearly outperforming conventional SSS.
- The eSSS method is not limited to the use of PCA vectors from empty MSR data, but can extend the SSS basis with other interference-characteristic spatial features, such as spatial patterns on narrow frequency band due to vibrations of MSR and the MEG system.

References:
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