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# Particle filters and RAP-MUSIC in MEG source modelling: A comparison

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**Abstract.** We compared the novel particle filtering approach to an established MEG inverse modelling algorithm "recursively applied and projected (RAP) MUSIC". Both methods are able to reconstruct temporally correlated sources in an automatic manner. We evaluated the performance of the two methods in critical yet neurophysiologically plausible source configurations. RAP-MUSIC outperformed particle filters when modelling sources of low signal-to-noise ratio or short duration, while the particle filtering approach performs better when reconstructing correlated sources or sources with positions and orientations varying across the response. 

*Keywords:* Magnetoencephalography; Inverse problem; Particle filters; RAP-MUSIC; Bayesian tracking

## 1. Introduction

In this paper we compare two methods for solving the magnetoencephalography (MEG) inverse problem in the multiple current dipoles framework: Recursively Applied and Projected MUltiple SIgnal Classification (RAP-MUSIC) and Particle Filters (PF). Both methods are, in principle, able to recover temporally correlated sources.

## 2. Methods

We approximate the neuronal current distribution in the brain as a sum of point-sources (current dipoles) and employ the spherically symmetric conductor model in the forward calculations [3].

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RAP-MUSIC [2] is a recursive extension of the MUSIC [1] algorithm. Its main steps are the diagonalization of the covariance matrix of the measurements and an iterative projection procedure which allows accounting for temporally correlated sources.

The input parameters of this method are the rank of the signal subspace (visually inferred from the eigenvalue plot of the covariance matrix) and a threshold value tuning the iteration.

Particle filters [4,5] are a numerical implementation of the Bayesian tracking algorithm where the probability density functions describing the source space (number of dipoles, dipole positions, orientations and strengths) are computed by means of a sampling–resampling procedure.

The input parameters of this method are the estimate of the noise covariance matrix and a transition parameter which regulates the time evolution of the source constellation.

We use four simulated data sets designed to mimic conditions difficult for inverse modelling methods yet encountered in real MEG data. The time series with the simulated sources and Gaussian noise was sampled every 1 ms.

## 3. Results

We compare the source reconstructions provided by the two methods by plotting the amplitude waveforms as well as superimposing the position and orientation of the reconstructed and original dipoles.

### 3.1. Short-lasting sources

The covariance matrix required by RAP-MUSIC should be estimated from a satisfactory number of samples; otherwise, the reconstruction could be unreliable. On the other hand, PF process the measurements one at a time yet taking advantage of the reconstruction at the previous time point. To test this, we simulated a source with a triangular amplitude profile, a 5-ms duration and a peak SNR of 5.1.

The result shown in Fig. 1 indicates that RAP-MUSIC correctly recovers short-lasting sources and outperforms PF in estimating the source amplitude.

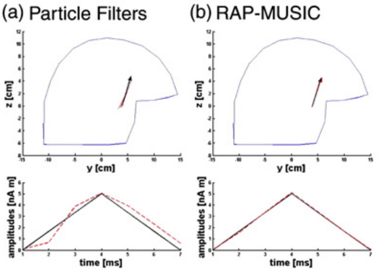


Fig. 1. PF and RAP-MUSIC reconstructions of a current dipole active for 5 ms.

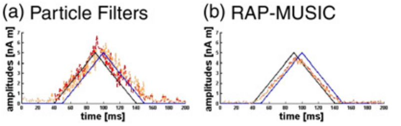


Fig. 2. PF and RAP-MUSIC reconstructions of two highly correlated sources; RAP-MUSIC reconstructs the two sources as being perfectly correlated. The distance between the sources is 6 cm.

### 3.2. *Quasi-correlated sources*

PF do not make assumptions on the temporal correlations of the neuronal sources; RAP-MUSIC has been developed to overcome MUSIC's inability to recover temporally correlated sources. Here we test the behaviour of the algorithms when two sources have identical temporal behaviour except for a small delay of 10 ms (Fig. 2).

In this case a single eigenvalue dominates and therefore RAP-MUSIC reconstructs the two sources as being perfectly correlated in time. The time delay is correctly recovered by RAP-MUSIC only by using *a priori* knowledge about the number of active regions and by overestimating the rank of the signal subspace.

### 3.3. *Low signal-to-noise ratio*

MEG measurements are characterized by a low signal-to-noise ratio (SNR). The dominant noise source is often the brain itself ("brain noise" due to the neural activity not of interest). We consider data with added white noise to yield SNR = 0.2 (Fig. 3).

RAP-MUSIC correctly recovers the position of the current dipole provided that the threshold is appropriately decreased (otherwise, no sources are found). The reconstructions by PF are less accurate both in terms of source position and amplitude waveform.

### 3.4. *Moving dipole*

When nearby sources are active in sequence the resulting field can be interpreted as that of a single moving dipole. We consider 20 equally strong dipoles distributed evenly along a line and each of which is active for 1 ms in sequence (Fig. 4).

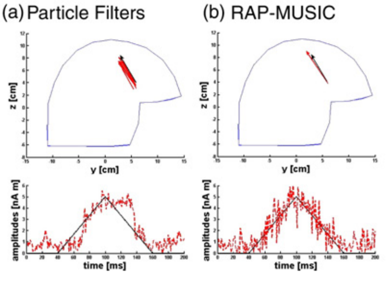


Fig. 3. PF and RAP-MUSIC reconstructions of a current dipole with a very low SNR.

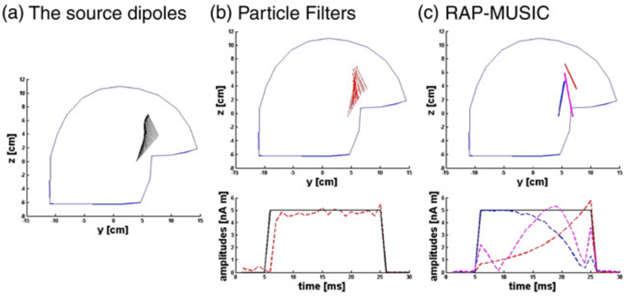


Fig. 4. (a) The true moving dipole; PF (b) and RAP (c) reconstructions.

PF correctly recover the positions, orientations and amplitudes of the sequence. RAP-MUSIC, which relies on the assumption of fixed source positions, estimates three different sources whose amplitude waveforms overlap.

## 4. Discussion

Both PF and RAP-MUSIC are able to recover point-like sources in difficult conditions such as with highly correlated sources, short-lasting activations and low SNR. With fixed sources, RAP-MUSIC is better than PF in the localization accuracy, particularly with low SNR, and gives smoother reconstructions of the source amplitude waveforms. Furthermore, its computational cost is significantly lower. On the other hand, PF outperform RAP-MUSIC when the sources are highly correlated. The most important advantage of PF over RAP-MUSIC is their ability to reconstruct sources whose position and orientation varies. This additional degree of freedom probably also accounts for the inferior performance of PF compared to RAP-MUSIC when estimating fixed sources.

Finally, PF is automatic and general, that is, no *a priori* knowledge on the number of sources or their SNRs is required.

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