

Gradient noise cancelling for simultaneous EEG-fMRI recording

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Introduction

Simultaneous Imaging for Tomographic Electrophysiology (SITE), or simultaneous EEG-fMRI recording, is becoming an important tool for correlating electrophysiological changes with hemodynamic changes in the brain. EEG data recorded during fMRI acquisition is contaminated with large gradient, RF pulse, and cardiac pulse artifacts. Hence, effective artifact removal is essential for SITE. Because RF and gradient artifacts are periodical, they are commonly removed by average waveform subtraction methods. However, since spectra of these artifacts include frequency bands much higher than common EEG sampling rates, average waveform subtraction requires EEG sampling timing correction beforehand. EEG sampling time correction involves recording of exact image acquisition timings, interpolation of EEG data, and re-sampling of EEG data synchronized with image acquisition. Such operation is computationally intensive and not suited for online artifact removal.

Method

We implemented an artifact reduction based on noise canceling using signals from dummy leads that do not carry bioelectrical signals. An advantage of this approach is that since signals from the electrodes and signals from dummy leads are sampled at the same time, noise subtraction does not require timing correction. We used two kinds of dummy leads: (1) dummy leads with loops that closely follow the loops formed by electrode pairs and the scalp, and (2) three mutually orthogonal loops that detect gradient field change (Fig. 1). Another feature of our EEG recording system is that the RF artifact is eliminated by using appropriate hardware. We found that carbon leads that are commonly used in MR compatible EEG system give rise to RF artifact due to RF non-linearity at the carbon-metal interface. By using copper cable combined with RF filters, we reduced the RF artifact sub-microvolt level. Dummy leads and an electrode pair (positions C4-CP4) were placed on a cap. The cap was placed on a water phantom that was covered with a paper dipped in 10% KCl solution. EEG gel was applied to ensure the conduction between electrodes and the wet paper. Signals from the dummy leads and the electrode pair were connected through a filtration panel, RF filters, and in-house built low-pass filters (bipolar inputs, Butterworth 125 Hz roll off) before they were recorded using an EEG recorder (NeuroScan NuAmps). A 3T MRI scanner (Siemens Trio) was used for the experiment. An echo-planar image sequence was applied (TR/TE=1550/30 ms, 25 6mm slices with no gap, 64x64 matrix) and the EEG was recorded for two minutes.

Results

With tight bipolar wiring and RF artifact-free recording, the artifact caused by MR scanning at the electrode pair before noise canceling was 290 micro-volts RMS. Using signals from gradient detectors, the noise level was reduced to 4.9 micro-volts RMS (Fig. 2a). By including the signal from a dummy lead affixed to the pair of electrodes, the noise level was further reduced to 3.3 micro-volts RMS (Fig. 2b). It appears that the use of a signal from a dummy lead affixed to an electrode pair reduced low frequency components that were caused by mechanical vibrations of the electrodes. Although we implemented noise canceling off-line, the noise canceling algorithm is incremental and thus easily be realized by a real-time software or by a hardware.

Conclusion

We demonstrated that noise canceling using dummy leads affixed to the electrodes and gradient detector loops can be used to remove gradient artifacts effectively. We also demonstrated that the RF pulse artifact can be eliminated by use of appropriate hardware.

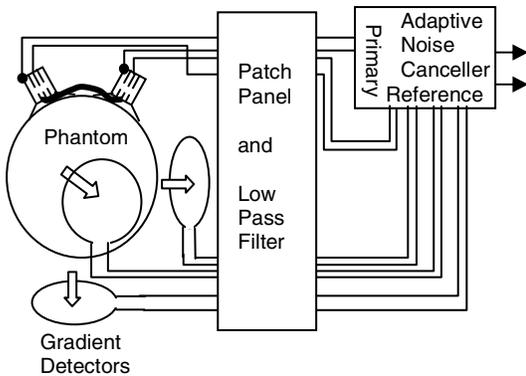


Fig. 1 Gradient Noise Canceling System

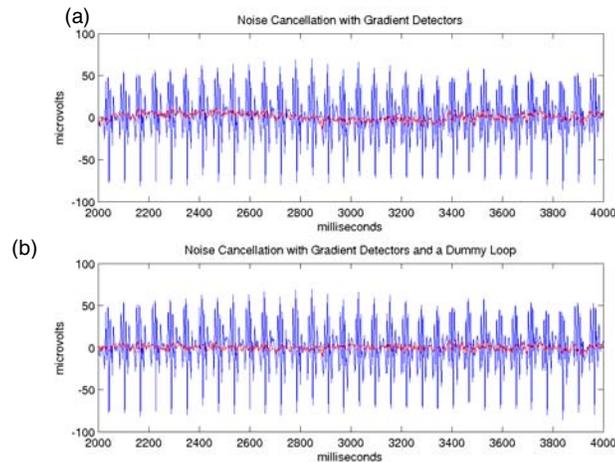


Fig. 2 Effects of Gradient Noise Canceling

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References

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