An Adaptive Cardio-Respiratory Filter for MRI Time Series Data

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Introduction: The cardiac cycle (CC) and respiratory cycle (RC) cause artifacts that affect time series data in fMRI, cardiac- or temperature imaging. In fMRI experiments, periodic signal fluctuations affect temporal stability and therefore result in decreased t-score. Also, these artifacts can result in temporal signal correlation of otherwise uncorrelated cortical areas, affecting e.g. event-related fMRI or rest-data analysis. Provided the timing of CC and RC is known, temporal signal stability can be improved by band-rejection filtering [1]. However, in practice, CC and RC are undersampled, complicating the separation of desired and unwanted signals. An alternative is the use of Fourier series fitting of the signals related to CC and RC [2], and subtracting the result from the data. In the following, a variation of this approach is presented that does not require model fitting, and is insensitive to variations in the period of CC or RC.

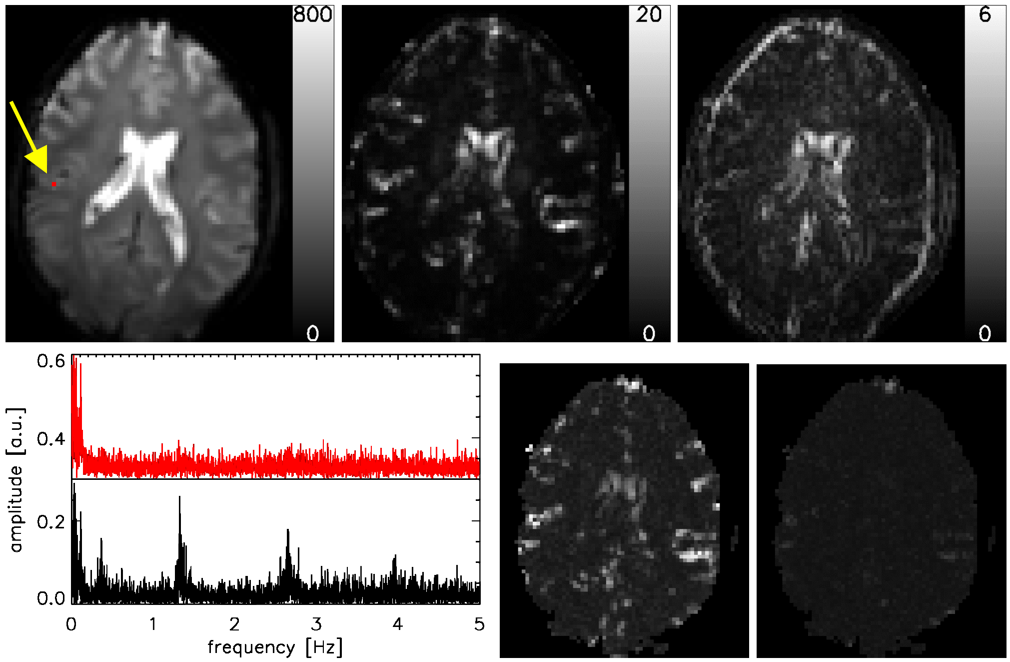

Figure 1: *Top row: Intensity image (left), cardiac correction maximal intensity projection (MIP) over the bins (center) and respiratory correction MIP (right). The plot shows the frequency spectrum from a single pixel in the 100-ms data, indicated in red in the intensity image. The spectrum is shown both before (black) and after (red) filtering (0.3 a.u. offset for figure clarity). The lower images show the maximal intensity found in the spectral range encompassing the principal frequency band of the cardiac artifact (1.25-1.46 Hz), both before (left) and after (right) filtering. Note the similarities with the cardiac correction MIP and the substantial decrease in artifact intensity after filtering.*

Materials and Methods: In order to accurately determine the temporal characteristics of the artifact ('event') through averaging, the event is subdivided in discrete timing intervals ('bins'). For each MRI volume, its acquisition time relative to the nearest event is computed to determine its corresponding bin. Data belonging to the same bin are averaged. Each MRI volume is corrected by subtraction of the corresponding bin in the correction data. The method removes signals correlated with CC or RC even when undersampled. Performance was evaluated on a GE 3 T scanner. A 17-slice dataset with 1.7 s TR and 90º flip angle was acquired (366 volumes; 622.2 s acquisition time; 45 ms TE; $2.3\times2.3\times3.0$ mm^3 nominal resolution; labeled 'slow'), resembling a typical fMRI experiment. CC and RC were recorded using a pulse oximeter and respiratory bellow. To assess performance, a single-slice dataset was acquired using a 100 ms TR (6222 volumes; 15º flip angle; 'fast'). The fast scan, aligned to the center slice of 'slow', ensured unaliased acquisition of CC and RC. Filtering was performed using 32 bins, duration of which was automatically determined from event spacing.

Results and Discussion: The method proved very effective in filtering both CC and RC artifacts (Fig. 1). Although in most of the brain both corrections are negligible, in some voxels, suspect of containing CSF or veins, the correction reached 3% of the baseline signal. In these voxels, both respiratory (~ 0.3 Hz) and cardiac (~ 1.3 Hz, and harmonics at ~ 2.6 Hz and ~ 3.9 Hz) signals are suppressed to approximately noise level (Fig 1, plot). The frequency spectrum is otherwise unaffected by filtering, and the noise level in the spectral range where cardiac and respiratory peaks were present is not significantly decreased, as would be the case for band-rejection filtering. The level of artifact suppression is further demonstrated by the two figures in the bottom row of Fig 1. In approximately 500 voxels, where artifact amplitude exceeded 5 standard deviations (SDs) (maximal artifact amplitude: 32.7 SDs (cardiac), 22.3 SDs (respiration)), the filter brought the artifact level down to below 4 SDs in 92.4% (cardiac) and 97.8% (respiration) of those voxels.

Conclusion: A flexible adaptive filter for MRI time series data has been demonstrated in an fMRI-like setting. It provides artifact suppression to noise level with no significant effect on signals unrelated to the cardiac and respiratory cycle.

References: [1] Biswal B, DeYoe EA, Hyde JS, Magn Reson Med 35:107-113 (1996); [2] Glover GH, Li T-Q, Ress D, Magn Reson Med 44:162-167 (2000)