cardioX: Short-time localized sliding estimate of cardiac component for physiological noise removal in fMRI

Christine Law[1]

[1]*University of Oxford, Oxford, Oxfordshire, United Kingdom*

Target audience: Neuroscientists, fMRI researchers

Purpose: Short-time localized sliding estimate of cardiac component for physiological noise removal in fMRI. The conventional technique for physiological noise reduction in fMRI uses Fourier analysis over long duration usually spanning the entire record [1-3]. We propose, instead, a sliding window technique (cardioX) that more closely approximates the cardiac component variation over the short term. CardioX removes more cardiac energy in its frequency band than the conventional method.

Methods: Any non-neuronal induced signal variation, including cardiac and respiratory related signal fluctuation, is not desirable and should be minimized in fMRI. Repetition time (TR) is often longer than the cardiac period. Thus, cardiac signal component is aliased and cannot be identified without ambiguity. The most common technique to remove cardiac physiological noise is RETROICOR [1] that reorders every data point, from a voxel time series, according to its relative phase with respect to the average cardiac cycle. The physiological noise component is obtained by fitting a low-order Fourier series to all these phases. Finally, the physiological component is removed by subtracting this Fourier series from the measurement.

We developed a novel technique (cardioX) that further reduces cardiac noise components. Like RETROICOR, our technique requires acquisition of cardiac waveform via photoplethysmograph. Cardiac cycle periods τ are obtained by differencing adjacent R-wave peaks in the cardiac waveform. The cardiac component of each τ is approximated by a dc component and two low-frequency sine/cosine terms. Windowed signal *y*, of duration N τ, is used to estimate the coefficients at each τ (N is typically between 5 to 60, depending on TR). For the next period of τ, the N τ signal window is slid by an increment of one τ.

For each N τ data-period, the sine and cosine coefficients are found by 1-norm minimization of $Ah - y$ (where *A* is a skinny matrix comprising time-shifted sine/cosine basis functions, *h* is the unknown coefficient vector, and *y* is the measurement). The next set of coefficients is found by repeating the optimization using a *y* data window slid by one τ. Matrix *A*, for that data window, holds time-shifted sine/cosine basis functions synchronized to the cardiac phase (fig.1). After all coefficients are found, matrix *D* is formed as in fig.2. (Basically, *D* comprises all the skinny *A* matrices. Each *A* is associated with a particular N τ duration signal window.) The cardiac contribution *y_c* for the entire record is approximated by multiplication of *D* and *h_big.* (Vector *h_big* is formed by stacking solution *h* for each signal window.) Finally, the cardiac noise in the measurement is removed by subtracting *y_c* from measurement *y*.

Results: To validate our technique, we collected data using a short TR (0.3s) for one slice in order to prevent cardiac signal aliasing. Scan was carried out on a Siemens Verino 3T (32 channel coil, GRAPPA=2, matrix/ TR/ TE/ TH/ FOV = 96x96/ 0.3s/ 35ms/ 4mm/ 22cm). Cardiac cycles and scanner trigger timing were collected via a photoplethysmograph on subject's right index finger. Data was processed in 3 ways: (1) no physiological noise correction, (2) cardiac noise reduction using RETROICOR, and (3) cardiac noise reduction using cardioX. Data were processed offline using FSL [4] and Matlab. Spectral content of each voxel was obtained by FFT of its time series. Figure 3 shows one pixel's spectral content. While RETROICOR removes much of the cardiac noise, cardioX reduces energy of the cardiac component even further.

Discussion: In general, cardiac pulsation is nonstationary. Conventional techniques, that use an entire data record for estimating cardiac contribution, cannot account for short-term variation. The proposed technique cardioX, utilizing a local sliding window to account for cardiac fluctuation, allows for more complete removal of cardiac signal.

Conclusion: We demonstrated a novel technique that further reduces cardiac fluctuation noise in fMRI signal over the conventional method. This technique cardioX relaxes the stationary-signal assumption imposed by the conventional technique. CardioX can mitigate other quasi-periodic components; *e.g.* respiratory fluctuation.

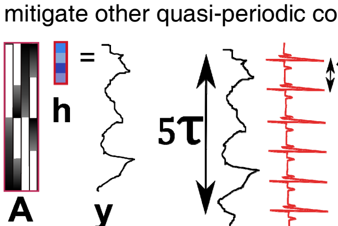

Fig 1.
(right to left)

Cardiac signal with time-varying period τ. Data length of N τ from measurement *y* (N=5) is used to estimate coefficient vector *h*. Matrix *A* comprises basis functions whose phases are synchronized with heart rate.

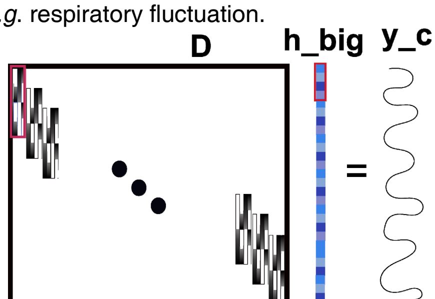

Fig 2. Matrix *D* comprises matrices *A* used in sliding-window calculation of *h*. *h_big* results from stacking *h* solution from each N τ window. Cardiac component of entire record is estimated as *y_c*.

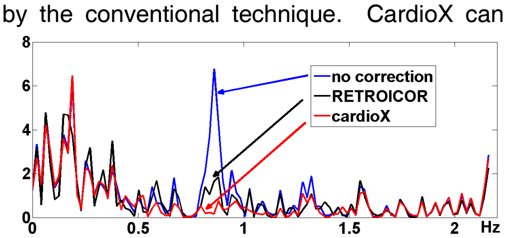

Fig 3. Spectral component of one voxel taken from a resting-state short TR (0.3s) scan. CardioX removes more cardiac component than RETROICOR.

References: [1] Glover et al. MRM 44:162-7. [2] Hu et al. MRM 31:495-503. [3] Corfield et al. Journal Applied Physiology 86:1468-77. [4] www.fmrib.ox.ac.uk/fsl