

Navigator Filtering Using Principal Component Analysis.

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Introduction: The acquisition of Cardiac MR volumes usually requires monitoring diaphragmatic motion to correct for breathing artifacts. In particular navigator echoes and self-respiratory techniques (k_0 profiles) can be used to acquire static high-resolution or cine images respectively. However, undesired cardiac motion, field inhomogeneities and high adipose fat signal may reduce the quality of the navigator projections leading to an erroneous and noisy estimation of the respiratory signal. Low pass filter can be used to eliminate the noise [1], but its inherent response delay makes this approach difficult to realize for real time prospective gating [2]. Recently, a methodology for real time navigator processing using Kalman filtering was proposed [3]. However, this approach requires an explicit model for breathing motion obtained from external sensors (e.g. bellows). Moreover, changes of the breathing pattern that differed from the model could lead to an erroneous output. To overcome this problem, we propose a novel approach for filtering the navigator projections rather than the respiratory signal using Principal Component Analysis (PCA). This original method was applied successfully to remove unwanted signals in the projections, and consequently an improved respiratory signal was obtained. Moreover, the proposed approach does not need an explicit model and has a great potential to be implemented in real time.

Theory: PCA is an orthogonal linear transform usually used to reduce dimensionality of the data by retaining those characteristics that contributes most to its variance. This process is equivalent to finding the singular value decomposition of a matrix $\mathbf{A} = \mathbf{U}\mathbf{S}\mathbf{V}^T$ and then projecting \mathbf{A} into a reduced space defined by only m singular values $\tilde{\mathbf{A}} = \tilde{\mathbf{U}}\tilde{\mathbf{S}}\tilde{\mathbf{V}}^T$. We proposed to apply this theory for reduction of unwanted signals in the navigator projections. In this case the rows and columns of a matrix \mathbf{A} correspond to n pixels and t samples of the navigator projection \mathbf{p} respectively: $\mathbf{A} = [\tilde{\mathbf{p}}_1, \tilde{\mathbf{p}}_2, \tilde{\mathbf{p}}_3, \dots, \tilde{\mathbf{p}}_t]$. Once the matrix \mathbf{U} is calculated a single projection can then be projected into the reduced space by $\tilde{\mathbf{p}}_r = \tilde{\mathbf{U}}\tilde{\mathbf{U}}^T\mathbf{p}_r(1)$.

Method: *Experiments* were performed in a Philips Achieva 1.5T scanner using a 5 channel cardiac coil. A non-angulated b-SSFP cine acquisition of the whole heart and great vessels was acquired in 5 volunteers with a previously described self-navigated sequence [3]. From this data, navigator projections were obtained from k_0 profiles every 50 ms. *Filtering.* A single value decomposition of navigator projections along time (over 200 samples) was calculated using Matlab. This was done for each of the 5 channel coils separately. For each coil the matrix $\tilde{\mathbf{U}}$ was then formed with a subsample of singular vectors, m . Consecutively, each of the 400 following projections was filtered using (1). The actual displacement due to respiration was obtained by determining the maximum of a cross correlation function between a reference projection obtained in expiration with the rest of projections. Analysis of the maximum values provides information about the quality of the displacement determination. This process was done for each coil for the filtered and non-filtered profiles.

Results. Figure 1a) shows the unfiltered projections in one volunteer. Calculations of the SVD took 40 ms on a singular computer, which can easily be implemented in real time. Figure 1.b) shows the first 13 (of 128) singular values mean and variance (across coils) for the different 5 volunteers. There is a noticeable similar and fast decay of singular values across all volunteers. Figure 1c) shows the first three associated temporal modes (first 3 columns of \mathbf{V}) for one coil in one volunteer. For this volunteer, the second temporal mode (bold line) had the same frequency as the breathing motion. Indeed, we found in all volunteers that either the second or third temporal mode was related to respiratory motion. Furthermore, figure 1c,d,e. show the original projection filtered by the proposed method for different numbers of singular vectors. Notice the quality of the projections was improved by using only the first 4 singular. Figure 2a,b shows the breathing signal obtained with the unfiltered and filtered profiles. Notice that using the non-filtered projections led to erroneous estimation of the respiratory motion, however, when using the filtered projection, robust respiratory displacements were obtained in most coils. The last column of figure 2 shows that the maximum of the cross correlation function is increased for the filtered (bold line) compared to unfiltered profiles (light line). Consequently, more reliable displacements were determined. This is confirmed in table 1, which shows the standard deviation of the respiratory displacements was much higher when using the non-filtered projections.

Discussion. In this abstract we have proposed a novel method for filtering navigator projections that can be implemented in real time. The main advantage of the method is that does not require any explicit model of the breathing motion and changes of the breathing pattern can be addressed by re-calculating the SVD matrices in a sliding windows manner [4]. We demonstrated the utility of the method by removing unwanted signals from projection obtained from k_0 profiles, however the same technique is applicable to any other navigator projection, (e.g to navigator echoes when using high field scanners).

References. 1.- Buehrer et al, MRM 2008, 2.- Uribe et al MRM, 2007, 3.- Spincemaille et al, MRM 2008. 4.- Badeau et al, IEEE 2004

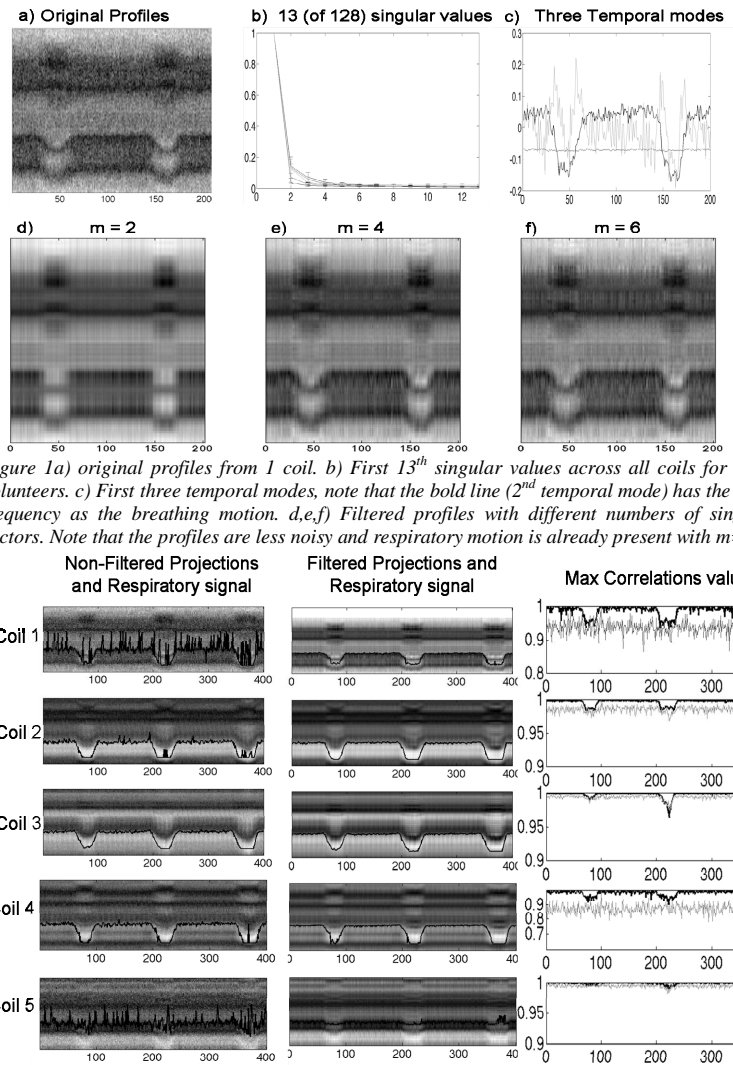


Figure 2. Filtered and non filtered projections with their respective respiratory signals. Last column shows the correlation values at the derived respiratory positions. It can be observed that using the filtered projections (bold line) the correlation values are higher, less noisy and concordant with the respiratory phase.

Coil nr	Respiratory signal from non-filtered projections stdv [mm]	Respiratory signal from filtered projections stdv[mm]
1	11.32	1.04
2	3.02	1.15
3	2.06	0.57
4	7.76	1.88
5	1.67	1.95