Temporal Filtering Effects in Auto-Calibrating TSENSE

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INTRODUCTION

The auto-calibrating TSENSE method [1] may lead to temporal filtering in the form of signal nulls in the temporal spectra of the dynamic SENSE images due to errors in the coil sensitivity estimates. The TGRAPPA [2] reconstruction using the same data has no temporal nulls but does not meet the pixel-wise optimum SNR that the SENSE method does. A hybrid method is proposed which combines TSENSE and TGRAPPA to achieve improved SNR without undesired temporal filtering.

METHODS

A low temporal resolution image used to estimate coil sensitivities and for SNR based regularization is calculated by integration or filtering of the aliased images in the auto-calibrating TSENSE method (Fig. 1). Sensitivities may be estimated simply by normalization by the root-sum-of-squares magnitude or by adaptive combining with spatial smoothing [3].

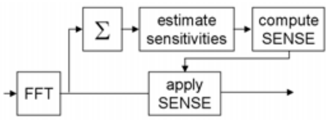

Figure 1. Auto-calibrating TSENSE method.

Errors in the unaliased images result from components of the aliased images that overlap with the DC (Fig 2) thereby protecting these spectra components [4]. These seemingly small errors may result in suppressing these components in the final output dynamic images. The TGRAPPA approach does not exhibit this temporal filtering and may be used to estimate unaliased images without these errors (Fig 3) thus mitigating the undesired filtering in the TSENSE reconstruction.

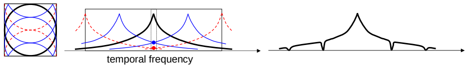

Figure 2. Temporal spectra for desired (black) and aliased (blue & red) images (left) illustrating the aliased spectral components (center) that fall within band around DC for TSENSE R=4 acquisition order. Spectral nulls may result in dynamic images (right) unless adequate spatial smoothing is employed.

The time series of multicoil images $g_i(x,y,t)$ may be written as:

$$g_i(x,y,t) = \sum_{k=0}^{R-1} S_i(x, y-kD)\, f(x, y-kD, t) e^{i2\pi kt/R}$$

where $S_i(x,y)$ denotes the coil sensitivities, f(x,y) the desired magnetization image, and D = FOV/R is the alias ghost spacing for rate R undersampling (t=0,1,2,…). The "unaliased" temporal average

$$\sum_t g_i(x,y,t) = S_i(x,y) \sum_t f(x,y,t) + errors$$

contains undesired spectral components of the aliased ghost images which lead to errors in the SENSE unmixing solution which implicitly cause temporal filtering of these components (comb notch) (Fig 2 right).

Cardiac images were acquired using a breath-held, prospective ECG-gated, segmented, trueFISP sequence. Full k-space acquisitions were used as a reference with full temporal resolution and were compared with spectra for parallel image reconstructions with rate R=4 undersampling. Data was acquired with 24 ms temporal resolution. Temporal spectra were measured in an elliptical ROI in the myocardium. The spectra for 40 pixels were combined using root-sum-of-squares to reduce statistical fluctuation.

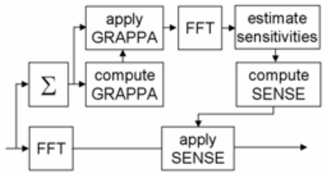

Figure 3. Proposed hybrid auto-calibration scheme using TGRAPPA & TSENSE.

RESULTS

Temporal spectra for various auto-calibration schemes are compared (Fig 4) with the reference spectra for a low SNR region in the myocardial wall (see image inset). Spectra are plotted on a logarithmic scale (dB=20$\log_{10}$(ampl)). Using the original TSENSE method without any spatial smoothing of the coil sensitivity maps, spectral nulls are evident at quarter band and band edge as indicated by arrows. The loss in SNR due to parallel imaging ($g\sqrt{R}$) is evident at the higher temporal frequencies which are noise limited in this region. The TGRAPPA method has no temporal nulls, but has a SNR loss of approximately 1.5-2 dB (20%) compared with TSENSE for this example. The proposed modified TSENSE method achieves the pixel-wise optimum SNR without temporal filtering.

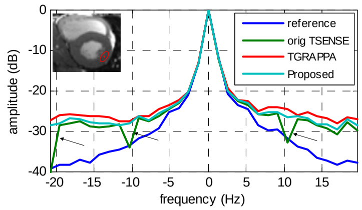

Figure 4. Temporal spectra (log scale) for myocardial ROI comparing auto-calibration methods for parallel imaging.

DISCUSSION

Estimation of sensitivity maps is a key to the performance of parallel imaging, and auto-calibration schemes are important in providing robust, easy to use implementations. However, one of the pitfalls of auto-calibration using temporal integration may be the undesired temporal filtering of the dynamic images which occurs implicitly in the SENSE reconstruction to due small errors in the coil sensitivities. Spatial smoothing of the raw coil sensitivities reduces the level of undesired temporal filtering. The TGRAPPA method that utilizes relatively low order k-space fitting with inherently spatial smoothed coil map estimates does not exhibit temporal filtering of the dynamic images series. The proposed method which uses TGRAPPA applied to the temporal average to estimate the coil maps used by TSENSE mitigates the temporal filtering and achieves the desired pixel-wise SNR optimization of SENSE.

REFERENCES

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