Self-Navigated 4D Respiratory Motion Imaging Using ESPReSSo Sampling and Reconstruction

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TARGET AUDIENCE

Researchers and physicians who are interested in capturing respiratory motion with high spatial resolution, e.g. for radiotherapy or multi-modal motion correction.

PURPOSE

To perform MR-based correction of non-rigid respiration-induced motion, it is essential to acquire a 4D motion model as quick and accurate as possible to minimize additional scan time. Approaches based on 2D imaging suffer from low resolution in slice-encoding direction. Genuine 3D imaging can achieve high resolution, but requires retrospective sorting of *k*-space into different respiratory phases. Furthermore, the required respiration signal is hard to acquire, since navigator scans use slice selective excitation, thus destroying the magnetization's steady-state in the imaging volume. We present a 4D imaging approach which is based on continuous, random acquisition of lines in a 3D *k*-space and is able to derive a navigator signal from the same data. The subsampled data are reconstructed using a Compressed Sensing (CS) method and achieves high acceleration factors.

METHODS

Data of a free-breathing subject is acquired continuously using a 3D spoiled gradient echo sequence (TE = 1.23ms, TR = 2.60ms, H-F frequency encoding, L-R phase encoding direction, matrix size = 256x256x72) which randomly samples a line in the k_y-k_z plane in each TR. A line can be thus measured multiple times dependent on the set total scan time and CS acceleration factor. Since tissue boundary integrity is highly desired for accurate motion detection, we use the Compr*e*ssed *S*ensing *P*a*r*tial *S*ubsampling (ESPReSSo) scheme [1] which enables better edge preservation than ordinary CS. Every 200 ms, a series of 8 navigator echoes (covering 8 phase encoding steps) is acquired in the *k*-space center. An exemplary sampling pattern ϕ of this approach is shown in Fig 1.

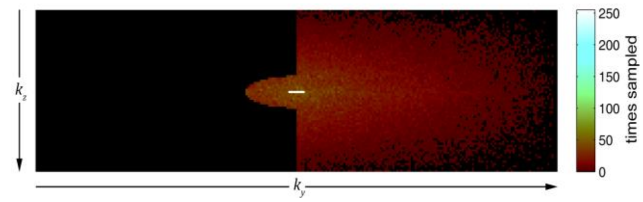

Fig. 1: The continuously acquired ESPReSSo sampling scheme for a period of 191 s. The bright line in the center consists of the navigator echoes.

The navigator scans allow the reconstruction of low-resolution images over time, from which a respiration signal is extracted. The analysis of the images' frequency contents in the range of the typical breathing frequencies (0.2 – 0.3 Hz), helps to roughly identify the navigator channels and the areas in L-R- and H-F-direction, which carry relevant information. The inverse Fourier transformation of the areas of interest provide projections of the moving liver dome from which the respiration signal is identified via the Laplacian of a Gaussian filter. Using this respiration signal, the *k*-space data (including the navigator data) can be sorted into a 4D *k*-space ν covering different respiration states. A trade-off between *k*-space subsampling and accuracy can be flexibly adjusted by tuning the acceptance windows around the centroids of the generated gates. It is also possible to use overlapping gates allowing view sharing and hence improvement of the resulting SNR.

The 4D image ρ is reconstructed via a FOCUSS [2] and POCS algorithm

$$\text{find } \rho = \Psi^{-1}(W \circ Q), \text{ to } \min_{Q} \|Q\|_F$$

$$\text{subject to} \left\| \nu - \phi \circ \mathrm{F}\left(\Psi^{-1}(W \circ Q)\right) \right\|_F \leq \varepsilon, \left(\Psi(G) - \mathrm{I}\right) \circ W \circ Q = 0,$$

$$\Omega_1 = \arg(\rho) \bigcap \Omega_2 = \mathrm{F}^{-1}\left[\mathrm{F}\left(\Psi^{-1}(W \circ Q)\right) \circ (1 - \phi) + \phi \circ \nu\right]$$

where Q denotes the sparse representation of the image over which the minimization via the sparsifying transformation Ψ, the Fourier transform F, the weighting matrix W and the GRAPPA calibration kernel G [3] is achieved.

The end-inspiratory state of the 4D image is registered and transformed using multilevel B-spline interpolation [4] to the end-expiratory state to produce a deformation field which is illustrated by the arrows in Fig. 2.

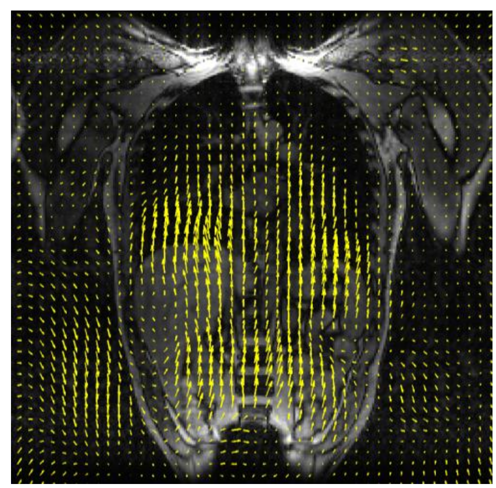

Fig. 2: Reconstructed coronal slice with deformation field.

RESULTS

Images which are reconstructed from complete datasets (total scan time 191 s) showed a nearly diagnostic image quality, even for a high number of gates with enabled view sharing, as it can be seen in Fig. 2 (images were not corrected for gradient distortions). When using only the first 60 s of a dataset, image quality was still sufficient for an accurate motion model generation.

DISCUSSION

The proposed method allows the generation of temporally and spatially highly-resolved 4D images. Furthermore, it allows very flexible trading between acquisition time, accuracy and image quality. Due to the possibility of view sharing, the number of reconstructed gates can be chosen as desired. The method provides an efficient way of incorporating a navigator. The proposed acquisition scheme and the k-space sorting integrate naturally into the CS framework. By means of ESPReSSo subsampling, a better edge preservation can be achieved in the same scan time than with conventional CS alone.

CONCLUSION

Due to its high flexibility and low scan time consumption, the presented approach has high relevance to researchers, who need an accurate and efficient way to acquire a model of non-rigid respiration-induced deformations in thorax and abdomen.

REFERENCES

[1] Küstner T, et al., *Proc Intl Soc Magn Med 2014*. [2] Gorodnitsky IF, et al., *IEEE Trans Signal Process* 1997;45(3):600-16. [3] Lustig M, et al., *Magn Reson Med* 2010;64(2):457-71. [4] Buerger C, et al., *Medical Image Analysis* 2011;15(4):551-64.