Highly Accelerated Dynamic 3D Hyperpolarized Lung Imaging

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Introduction

Dynamic hyperpolarized helium-3 imaging has been shown to provide assessment of air trapping in obstructive lung disease (1). A key requirement for imaging ventilation heterogeneity concerns dynamic volumetric coverage of the lung at sufficient spatiotemporal resolution. Recent work has demonstrated the feasibility of time-resolved 3D lung imaging using constrained image reconstruction from radially undersampled data (2). Based on the HYPR framework (3) a composite image is used as prior determining overall signal-to-noise performance and undersampling artefact suppression. While this approach has facilitated significant increases in scan efficiency it may also suffer from inaccuracies arising from inconsistent temporal averaging in the composite as a result of bulk motion occurring during respiratory manoeuvres.

Along a different line of development to accelerating image acquisition, spatiotemporal correlations may be exploited by using temporal basis functions derived from time-resolved data. Thereby the dynamic image information is decomposed into spatially depending weights and temporal frequency basis sets. Such an approach permits accommodation of bulk motion if it can be described by a linear combination of the available temporal basis functions. It has recently been demonstrated that temporal basis sets derived from low-resolution training data can be favourably used to accelerate dynamic image series of the heart (4). The present work introduces feedback-regularized *k-t* PCA for dynamic hyperpolarized gas imaging. It is demonstrated that the synergistic combination of partial Fourier and *k-t* sampling allows for more than 12-fold net increases in scan efficiency relative to fully sampled 3D lung imaging.

Methods

In *k-t* PCA the signal ρ is represented by a linear combination of temporal basis functions B(f) with corresponding spatial weightings w(x) whereas the basis set B and signal variance weights w_{train} are determined from low-resolution training data ρ_{train}. Matrix E contains the Fourier encoding coefficients and optionally coil sensitivity information; $\lambda\Psi$ is the weighted noise covariance matrix and vector ρ_{alias} stacks the undersampled data in the spatial-temporal frequency or x-f domain:

$$\rho(x_i, f_i) = B(f_i) \cdot w(x_i) \quad w_x = \left[\text{diag}(|w_{train,x}|^2)\right] E^H \left(E \left[\text{diag}(|w_{train,x}|^2)\right] E^H + \lambda\Psi\right)^{\dagger} \rho_{alias}$$

In order to acquire training and undersampled data, a variable density k-t undersampling scheme including an elliptical k-space shutter and partial Fourier sampling along k_y was implemented (Figure 1) on a 3T Philips Achieva system (Philips Healthcare, Best, The Netherlands). An elliptical transmit/receive quadrature birdcage was designed and built (Rapid Biomedical, Rimpar, Germany) to connect to the multi-nuclei channel of the system at 97.1 MHz. Helium-3 gas (Spectra Gases, UK) was polarized under regulatory licence to approximately 26% using a spin-exchange optical pumping apparatus (GE Healthcare). A volume of 300 ml of helium gas was mixed with 700 ml N_2 gas and administered using a Tedlar bag. Experiments in healthy subjects were conducted according to the local guidelines and after informed consent was obtained. Sequence parameters were as follows: field-of-view: 400x400x100 mm^3, matrix: 160x160x20, T_R/T_E: 4.0/1.2 ms, flip angle: 2 deg, spatial resolution: 2.5x2.5x5.0 mm^3, temporal resolution: 1.3 sec. Dynamic image data were acquired during a 35 second period upon inhalation of the gas.

In image reconstruction the temporal average of all data was used as initial estimate for feedback regularization in *k-t* PCA. The reconstruction code was implemented using Matlab (Mathworks, Natick, USA)) on standard PC hardware. Two iterations were performed resulting in a total reconstruction time of 10 min for the dynamic 3D data acquired.

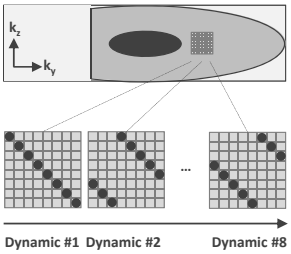

Figure 1: Variable density dynamic sampling patterns. The central shutter (dark grey) samples 47 training profiles at full field-of-view.

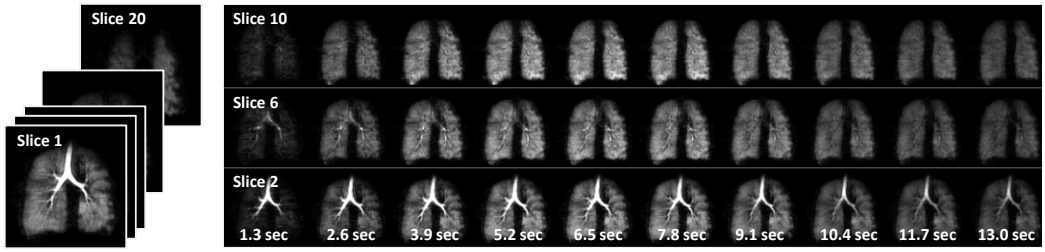

Figure 2: Dynamic 3D data of a healthy lung reconstructed from 8-fold undersampled data acquired during gas inhalation and wash-out. Data were recorded using an elliptical quadrature birdcage at a 3T system. Out of the total of 20 acquired slices three exemplary dynamic sets are shown illustrating excellent signal-to-noise performance at an acquired resolution of 2.5x2.5x5.0 mm^3 with a temporal update rate of 0.77 sec^{-1}.

Results

The undersampling scheme was successfully implemented and tested on the system. Figure 2 demonstrates consecutive dynamic frames for three out of the total of twenty acquired slices during gas uptake and washout. Considering the amount of data undersampling employed, excellent signal-to-noise and un-aliasing performance was achieved. Image artifacts from bulk motion of the lung were not observed. Feedback regularization efficiently suppressed background signals enhancing reconstruction performance in low signal regions as present during gas wash-out.

Discussion

This work has demonstrated that significant data undersampling using the *k-t* PCA approach can successfully be applied to dynamic and volumetric imaging of lung ventilation. More than 12-fold net acceleration relative to conventional fully sampled 3D Cartesian data acquisitions has been achieved with a single channel volume receive coil. The method is considered promising for studying air trapping and gas washout kinetics in asthmatics and other obstructive lung diseases.

Acknowledgments

This work is supported by the Guy's and St Thomas' NHS Foundation Trust, King's College London's Biomedical Research Centre (BRC), EU FP6 Phelinet and the UK EPSRC grant ~ EP/D070252/1.

References

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