Improved Compressed Sensing reconstruction and optimised sampling patterns for very fast acquisition of Hyperpolarised 3He images

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Introduction Compressed Sensing (CS) [1] allows accelerated acquisition time with less RF encoding steps without the need for extra hardware such as parallel receiver array coils. This technique was recently introduced in hyperpolarised ^{3}He lung MRI [2] with promising results. Introduction of prior knowledge information can improve the convergence of the CS algorithm and hence the quality of reconstruction. In this work, we present an improved reconstruction method for undersampled ^{3}He hyperpolarised lung MRI images. This method uses anatomically matched boundary information from coregistered proton lung images acquired simultaneously as prior information for the CS reconstruction. Furthermore, the information on signal decay from view to view due to nonrecoverable hyperpolarisation of spin population is used to help design an optimal undersampling pattern.

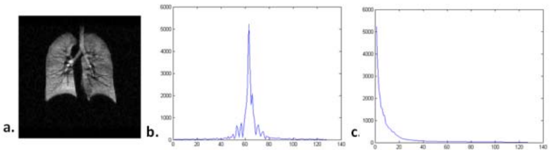

Figure 1: a) Fully sampled image. b) Projection over the centre of k-space in the phase encoding direction. c) Ordered phase encode lines depending on SNR

Materials and Methods The study was performed on two healthy volunteers at 3T (Philips, Achieva) with rapid switching between ^{3}He frequency (97 MHz) and proton frequency (128 MHz). A ^{1}H body coil (quadrature birdcage) was used as Transmit/Receive (T-R) and was detuned during ^{3}He T-R, while a prototype linear Helmholtz coil (PulseTeq, UK) was used for ^{3}He T-R. The volunteers inhaled a dose of 300ml of ^{3}He, polarised to ~ 25% with rubidium spin exchange apparatus (GE, USA) mixed with 700 ml N_2 in a 1 litre bag. Two scans were performed sequentially during the same breath-hold as described in [3] using 2D spoiled gradient echo sequence with sequential Cartesian phase encoding. The ^{3}He ventilation scan was performed first followed by ^{1}H lung anatomy scan from the same slice.This protocol was repeated three times to acquire fully sampled, 2× and 3× undersampled ^{3}He data. From the fully sampled ^{3}He data, a projection was plotted along the phase encode direction and was sorted according to decreasing SNR as described in [4] and shown in Figure 1. The phase encode lines giving the maximum signal were the only ones considered to generate 2× and 3× undersampling patterns with optimal sampling strategy that accounts for gas depolarisation. The registered ^{1}H images were inverted on a pixel-by-pixel basis, segmented to obtain high resolution masks of the lung boundaries and the major vessels, which was then implemented in the CS algorithm. Both simulations and prospective data acquisition were performed to test the performance of these two methods. First, a simulated 3× under-sampled ^{3}He image was reconstructed without and with the ^{1}H prior information respectively, then the performance of the generated patterns obtained from the knowledge of the k-space filter were tested against random 1D undersampling patterns generated as described in [1]. The resulting images were compared to the original fully sampled image for each case.

Results and Discussion Figure 2 shows an example of reconstruction obtained using the optimised 2× undersampled pattern which gives a better preservation of lung structure around the vessels. In fact, the difference image in Figure 2.e displays fewer reconstruction errors, in comparison with the reconstructed image using a normal 1D pattern in Figure 2.d. Similar results were obtained with a reduction factor of 3. With this strategy and by acquiring the most important high frequency lines first more weight is given to the high frequencies that determine the structure and edges of the object.

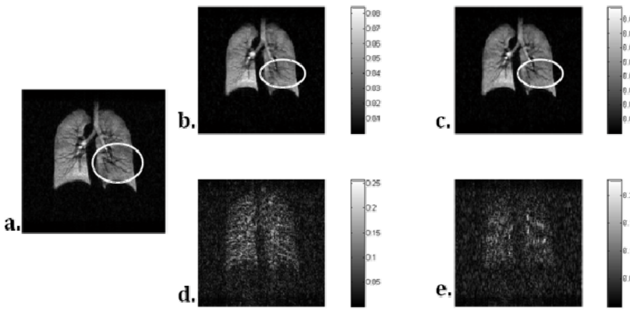

Figure 2: a) Fully sampled image. 2×undersampled image obtained from b) random, c) optimised patterns respectively. d,e) Corresponding difference images with the original fully sampled image

Simulation results are shown in Figure 3, 3× under-sampled images were reconstructed using the CS algorithm with (wP) and without addition of the prior information. In Figure 3 (e,f) difference images between the original fully sampled image and the reconstructed under-sampled images are shown, the respective root-mean square (RMS) differences were 0.21 and 0.16 with a gain of 24% over the whole image, with the new method. Improvement of the reconstruction, especially in the right lobe region, is shown in images (a,b,c) and in the line profiles plotted in Figure 3.d. When the two optimisation methods were combined, the effect of the optimal sampling pattern was the most dominant.

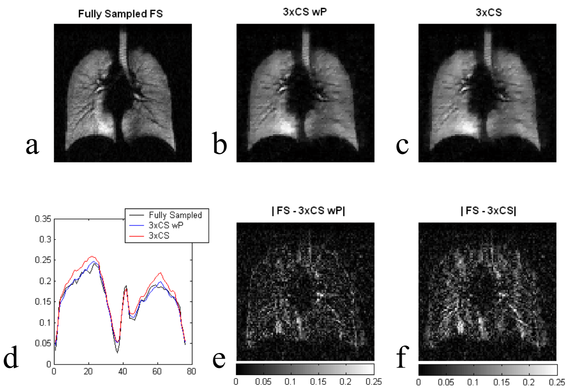

Figure 3: a) Fully sampled image. 3×undersampled image obtained b) with and c) without addition of ^{1}H MRI prior knowledge. e,f) Corresponding difference images with the original fully sampled image and d) line profile comparison over the whole lung region

Conclusions These preliminary results show that a good CS reconstruction of ^{3}He lung images can be achieved with a reduction factor up to 3 with a single coil by utilising the mutual information in the registered ^{1}H anatomical image with this method and knowledge of the k-space filter enabling a significant decrease in the reconstruction error.

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