Novel Sampling Strategy for Abdominal Imaging with Incomplete Breathholds

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Introduction: Respiratory motion is a common source of artifacts in MRI, especially in abdominal imaging. They can be minimized by breath-holding during the acquisition. However, the ability of patients to comply with predefined breathhold lengths varies greatly, often resulting in incomplete breathholds and thus motion artifacts. Previously, this problem has been addressed by using a center-out profile order, since respiratory motion tends to produce less severe artifacts when it occurs during the acquisition of the k-space periphery [1]. However, an overestimation of the actual breathhold length still leads to artifacts. In this work, a different profile order is proposed and explored, which supports the reconstruction of images from data acquired up to any point in time and thus the exclusion of data collected after the onset of respiratory motion. The amount of data available for the reconstruction is unknown in advance, like in some approaches to imaging during free breathing [2]. The profile order is based on a segmented acquisition with global sampling density variation and local Poisson disk (PD) sampling [3], and it is compatible with compressed sensing (CS) and parallel imaging (PI) for accelerated scanning, as well as adaptable to target functions of the spatial resolution over time.

Methods: The proposed profile order is described for 3D Cartesian imaging, in which case it is determined by the ordering in the k_y-k_z plane. First, an elliptical central area is fully sampled to minimize the risk of motion during its coverage. This permits PI with auto-calibration and takes typical distributions of the signal's energy into account. Then, the measurement is grouped into fractions of N samples each, which are acquired sequentially. Each fraction is formed by samples arranged in a variable density PD distribution over a restricted area in k-space (composed of a set of points S), corresponding to a restricted resolution. The restriction is imposed by a predefined maximum reduction factor R that affects the undersampling artifacts. The area in k-space is increased with time, until the final resolution is reached. The PD distribution provides incoherent aliasing and therefore permits reconstruction based on CS [4-6]. The variable density decays with distance from the k-space center and increases with time. The PD distribution is created by choosing samples from a possible subset P of S. A subset M of S has already been measured and forms a forbidden subset F around each element of M due to the minimum distance of samples. This leads to a set of possible samples $P = S \setminus (M \cup F)$ to choose from at random. After the selection, an update of P is required. Repetitions are performed, until the fraction contains N samples. Within each fraction, the acquisition order can be selected freely, thus permitting an optimization of the trajectory in k_y-k_z space, for instance to minimize the distance between subsequent samples and hence to reduce eddy-current induced artifacts.

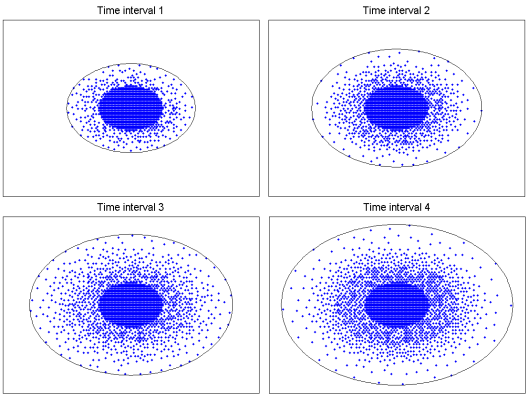

Fig. 1: Examples of sampling pattern generated with the proposed approach. Shown are the profiles acquired in the k_y-k_z plane up to four equidistant points in time.

Abdominal imaging was performed on volunteers on a 1.5T scanner (Philips Healthcare, Best, The Netherlands), using a 16-element torso coil. A T_1-weighted spoiled gradient-echo sequence with a TE/TR of 2.3 ms/4.4 ms was employed to cover a typical FOV of 380 x 280 x 240 mm^3 with an actual spatial resolution of 1.5 x 1.5 x 3.0 mm^3 in 20 s for R=3, N=138, and 100 fractions. Within each fraction, the samples were measured sequentially according to their angle to a given axis. The same scan was repeated several times on each volunteer, who was instructed to start breathing at different points in time. Reconstructions were performed with L1-SPIRiT [7] retrospectively, using either all data, or only data acquired up to the onset of significant respiratory motion.

Results: An example of a generated pattern is given in Fig. 1 with a maximum reduction factor of R=8 and 40 fractions with N=347 samples each. A set of results of abdominal imaging from one volunteer is shown in Fig. 2. Within this figure, (b) and (d) from incomplete breathholds contain motion artifacts, visible also in the details. These artifacts are suppressed in (a) and (c), which were reconstructed from data acquired until the onset of respiratory motion. Reconstruction after 10s leads to recognizable reduced resolution that can be improved using a larger maximum reduction factor.

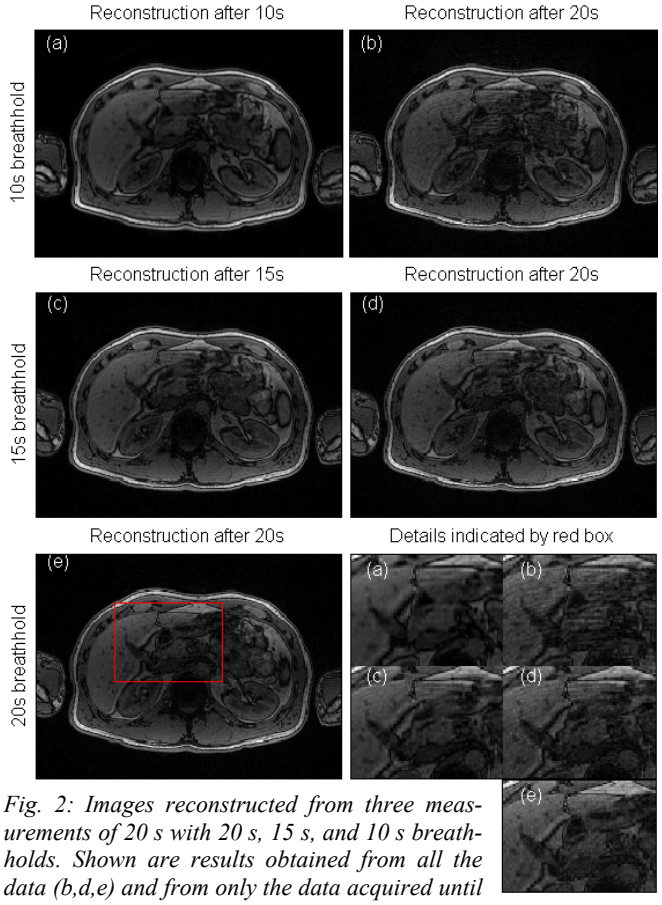

Fig. 2: Images reconstructed from three measurements of 20 s with 20 s, 15 s, and 10 s breathholds. Shown are results obtained from all the data (b,d,e) and from only the data acquired until the onset of respiratory motion (a,c,e).

Discussion: A novel approach to cope with incomplete breathholds in abdominal imaging was proposed. Instead of adapting the spatial resolution in advance based on an estimate of the breathhold length a particular patient is able to achieve, it is automatically increased during the scan. The target function is defined by a maximum sustainable reduction factor determining the artifact level. Once the maximum resolution is reached, the remaining scan time is used to reduce artifacts by decreasing the reduction factor, until the patient starts to breathe. The reconstruction adapts to the actually achieved breathhold length, which can be detected either by external sensors or navigators, or can be determined from a series of images reconstructed from different amounts of data and a suitable image quality criterion.

References: **[1]** Maki JH, et al. JMRI 1997; 7:1132-1139; **[2]** Doneva M, et al. Proc ISMRM 2011; 641; **[3]** Dunbar D, et al. Proc SIGGRAPH 2006; 503-508; **[4]** Candes E, et al. IEEE Tran Info Theo 2006; 52:489-509; **[5]** Donoho D, IEEE Tran Info Theo 2006; 52:1289-1306; **[6]** Lustig M, et al. MRM 2007; 6:1182-1195; **[7]** Lustig M, et al. Proc ISMRM 2009: 334.