A Robust Free-breathing Data Acquisition Method for Reduction of Respiratory Motion Artifacts

Yongwan Lim[1], Yeji Han[1], and HyunWook Park[1]
[1]*Department of Electrical Engineering, KAIST, Daejeon, Korea*

Target Audience
MR investigators who are interested in minimizing respiratory motion artifacts for abdominal imaging

Purpose
Abdominal magnetic resonance imaging (MRI) remains as a major challenge due to respiratory motions, which degrade image quality. To minimize the motion-related artifacts, a simple breath-hold approach is commonly employed at the cost of patients' inconvenience, but it can be rather challenging for some patients [1]. Recently, a free-breathing method for retrospective reconstruction based on the respiratory self-gating has been proposed as alternative [2], but acquisition timings of the adjacent phase encoding (PE) lines can be concentrated in non-quiescent respiratory phases (e.g. mid-inspiration), resulting in severe image artifacts. To overcome the problem, a robust data acquisition scheme based on a variable density sampling is presented in this abstract, where multiple signals of the same PE are equidistantly acquired and the consecutive PE steps are randomly distributed.

Methods
Motion Extraction: To extract the respiratory motion state, the self-navigated (NAV) technique [3] is embedded in a Cartesian 2D FLASH sequence, so that the NAV signal is acquired before each imaging signal. The signal of a single channel from multiple phased-array coils is selected, based on the coil positions, to obtain the most sensitive signal to respiratory motion. Then, the signal is band-pass filtered to eliminate the oscillation caused by the cardiac motion and to extract the information of respiratory motion only.
Data Acquisition: Since the motion states of the contrast-determining central PE lines are crucial for avoiding the motion artifacts, a variable density acquisition, whose distribution is determined by Gaussian function with an adjustable variance, is used to acquire the central PE lines more frequently than the outer PE lines. In addition, a PE ordering table is implemented with two principles. First, signals of the same PE step are equidistantly acquired over a predetermined respiratory period, T_{resp}. In Fig. 1 (a), seven signals of the same PE step are marked as blue dots and arrows. As illustrated by the corresponding blue dots in Fig. 1 (b), the same PE signals are acquired at different phases of a respiration period. Second, the ordering of the PE steps is incoherently traversed using a random generator, thereby preventing the adjacent PE lines from being densely acquired at non-quiescent respiratory phases.
Simulation: To validate the proposed method, a numerical phantom was designed with a matrix size of 192×192. As marked with the arrows in Fig. 2 (a), seven inner circles were modeled to reflect abdominal organ motions based on a pre-acquired self-NAV signal. The motion-influenced k-space data was generated by applying the motion state from the pre-acquired self-NAV signals of four healthy human volunteers.
***In-vivo* Experiments:** A multislice Cartesian 2D FLASH sequence was used to acquire data from five healthy volunteers at 3.0T MRI scanner (Magnetom Verio, Siemens Healthcare, Erlangen, Germany) using the following parameters: TR/TE = 129/7ms, flip angle = 70°, bandwidth = 390Hz/pixel, slice thickness = 5mm, matrix = 192×256, field of view = 232.5×310 mm^2, T_{resp} was pre-measured from each volunteer. The variance of Gaussian function for the variable density was fixed so that the central PE lines were acquired seven times and the outermost were acquired once. As a result, a total of 576 PE lines were acquired for each scan.

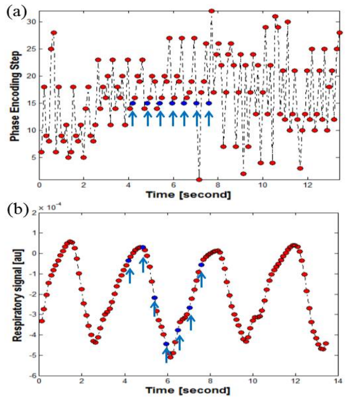

Figure 1. (a) An example of the PE steps of the proposed data acquisition scheme. (b) Self-NAV signals along time axis.

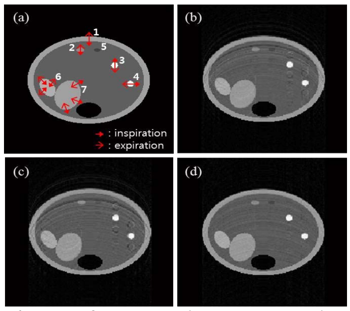

Figure 2. (a) Simulated motion phantom. Reconstructed images at end-expiration from (b) conventional 1, (c) conventional 2, and (d) the proposed methods.

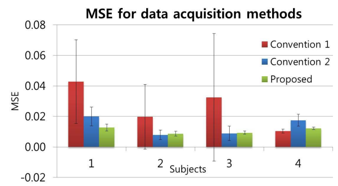

Figure 3. Relative MSE results of numerical simulation using self-NAV signals from four different subjects

Results and Discussion
Simulation: The proposed method was compared with other data acquisition methods: conventional 1 (uniform density and several repetition of linear PE order), and conventional 2 [2]. As shown in Fig. 2, severe ghost artifacts are observed from the elements of 2, 3, and 4 in the images reconstructed by the conventional methods, while the image reconstructed by the proposed method reduces the artifacts as shown in Fig. 2 (d). Furthermore, the proposed method preserves more fine details near element 5, which follows a sinusoidal intensity variation across the respiratory cycle. In Fig. 3, the statistical evaluations using the relative mean square errors (MSE) are presented, where the proposed method exhibits significantly lower standard deviations of MSE than others. Thus, the proposed data acquisition method provides improved image quality regardless of the different motion patterns.
***In-vivo* Experiments:** All the experiments were performed under the free-breathing condition except for the breath-hold images. Fig. 4 (a-d) shows representative axial images reconstructed from the retrospectively gated data at end-expiration from the breath-hold, conventional 1, 2, and the proposed method, respectively. The self-NAV signals along the PE axis are plotted in Fig. 4 (e-g), where the data marked with the red dots are used for image reconstructions. The central PE lines in Fig. 4 (e) are acquired far from end-expiration, thus resulting in crucial motion artifacts as shown in Fig. 4 (b). In addition to the fact that the proposed method results in an excellent delineation of organs, motion artifacts are less annoying in the images reconstructed by the proposed method since they appear as incoherent noise due to the randomly distributed sampling pattern (Fig. 4 (g)).

Conclusions
The proposed data acquisition method reduced motion artifacts by using a variable density and randomly distributed PE steps. It also allowed random sampling pattern after the gating procedure. The acquired data can be also used to reconstruct multiple images at different respiratory phases using advanced reconstruction algorithms, such as the compressed sensing technique.

References
[1] R. Song et al, JMRI, 33(1):143-148 (2011). [2] N. Jin et al, MRM, 66:207-212 (2011). [3] A. C. Brau et al, MRM, 55:263-270 (2006).

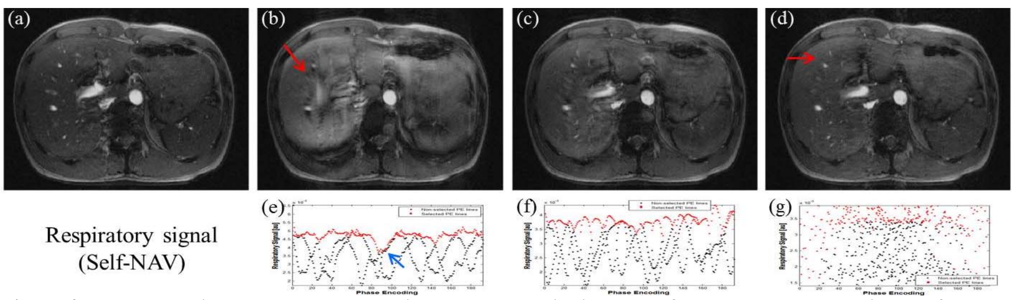

Figure 4. *In-vivo* experiments. (a) Breath-hold image at end-expiration as a reference. Reconstructed images from (b) conventional 1, (c) conventional 2, and (d) the proposed method, respectively. (e-g) The respiratory signals from self-NAV are plotted along PE axis. The images (b-d) are reconstructed from PE lines represented red dots in (e-g) and the black dots are discarded after retrospective gating procedure.