Free-Stop Scanning for 3D TSE

Guobin Li[1], Maxim Zaitsev[1], Esther Meyer[2], Dominik Paul[2], and Jürgen Hennig[1]
[1]*University Medical Center Freiburg, Freiburg, Germany,* [2]*Siemens Healthcare, Erlangen, Germany*

Introduction: The measurement time of 3D MR acquisitions with the turbo spin echo (TSE) sequence is usually up to several minutes, where patient motion often happens during the scanning. This leads to degrading of reconstructed image by motion artifacts. In the worst case, the 3D acquisition needs to be repeated. However, if motion occurs towards the end of data acquisition, most part of *k*-space data has been acquired without a corruption, it is then possible to reconstruct artifact-free images using only the 'consistent' raw data. Inspired by this thought, we have developed an acquisition scheme to address the motion problem in 3D TSE imaging, which consists of dedicated designs for the *k*-space sampling pattern, view reordering, and real-time motion monitoring.

Methods: *K*-space sampling pattern: The complete acquisition is a gridded Poisson-disk sampling in $k_y - k_z$ plane for Compressed Sensing (CS) reconstruction [1, 2], which is the combination of two parts: basic acquisition and complementary acquisition (see Fig.1). The basic acquisition is also a gridded Poisson-disk sampling, but with a smaller sampling factor. In the complementary acquisition, the missing data to the complete acquisition are acquired. All data of the basic acquisition are acquired at the beginning of the scan immediately followed by the complementary acquisition. View reordering: The reordering scheme in the basic acquisition and the complementary acquisition is prepared separately. Interleaved radial reordering with constrained random trajectories is applied in both basic and complementary acquisition [3], where the *k*-space sampling mask is divided into multiple sectors, and filled by echo trains in an interleaving manner (see Fig.2). Within each sector, echo train trajectories are randomized. This optimized reordering makes sure that the *k*-space is uniformly filled whenever the acquisition stops. Motion monitoring: In each echo train, the first echo is acquired using frequency encoding only, which serves as a navigator for motion detection [4]. After inverse Fourier transform, a projected profile of the object is obtained. By real-time comparison of the acquired profile with a reference taken at the beginning, patient movement is detected. Scanning is stopped immediately whenever motion happens. The profile comparison is quantitatively performed using the following formula to calculate the similarity s: $s = 1.0 - (|a-b|)/max(a,b)$. If motion occurs in the phase of basic acquisition, no image will be reconstructed, and the 3D acquisition needs to be repeated. If motion occurs at any time of the complementary acquisition, images without motion artifacts will be reconstructed by the CS method. Experiments: The concept has been implemented for a 3D TSE sequence with variable refocusing flip angles (aka. SPACE), and tested on a 1.5T MR scanner (Magnetom Symphony, Siemens, Erlangen, Germany) with the following parameters: Knee imaging with a single channel coil; image matrix [SL x PE x RO] = [176 x 236 x 256]; TR/TE = 1300ms/35ms; Echo train length = 44; *k*-space sampling factor for the complete acquisition = 35%; *k*-space sampling factor for the basic acquisition = 12%; For experimental validation, scanning was not stopped when motion happened in this experiment; total acquisition time is 6min34sec. Motion was retrospectively detected by comparing calculated similarities of acquired profiles. A 5-period simple moving average was performed to smooth out short-term fluctuations in the similarity curve. Images were first reconstructed with all acquired data, and then reconstructed again after discarding the data acquired after the occurrence of the first significant motion.

Results and Discussion: In the knee examination, motion was detected by the 206th navigator (see Fig.3), which means that 69% of the complete acquisition has been finished without motion. As shown in Fig.4 b) ~d), images reconstructed with all data were strongly contaminated by motion artifacts. However, if the acquisition stops immediately when motion is detected by navigators, clean images can be reconstructed (see Fig f) ~h)). The amount of data acquired in basic acquisition is determined empirically by the lowest acceptable image quality. The direction of frequency encoding can be adjusted from scan to scan to increase the sensitivity of navigators to often occurred motions. This acquisition scheme is also compatible with flexible linear reordering for T2-weighted imaging. External devices can be used for monitoring of object motion, for example optical sensor, or breathing belt etc.

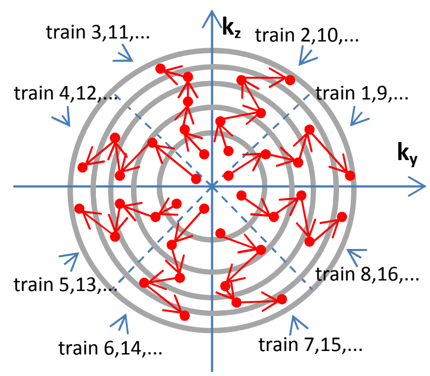

Fig.2 an illustration of the interleaved radial reordering with constrained random trajectories, where echo train length is 5 and the *k*-space mask is divided into 8 sectors.

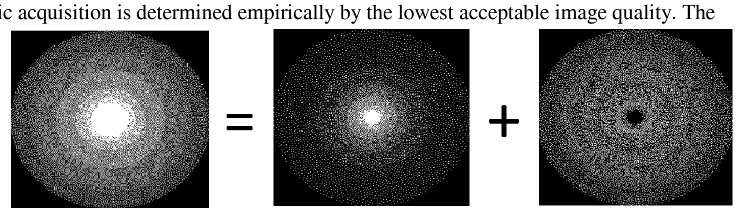

Fig.1 The complete acquisition (left) consists of two parts: basic acquisition (middle) and complementary acquisition (right).

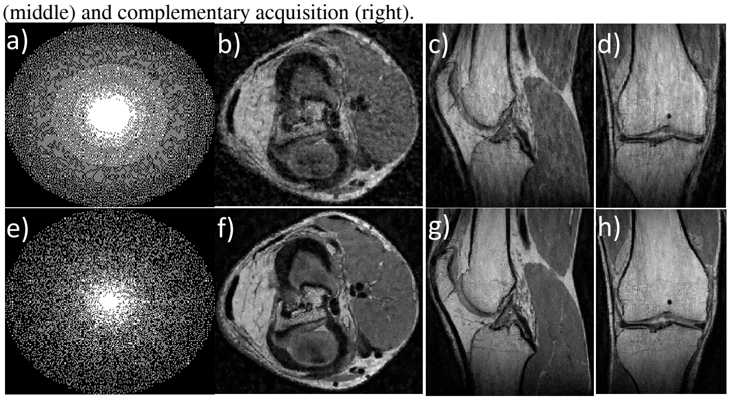

Fig.4 a) is the *k*-space sampling mask of the complete acquisition; b) ~d) are three perpendicular slices reconstructed with all acquired data; e) is a mask showing the actually acquired *k*-space data before motion occurred; f) ~h) are the same slices as in b)~d), but reconstructed without motion corrupted data.

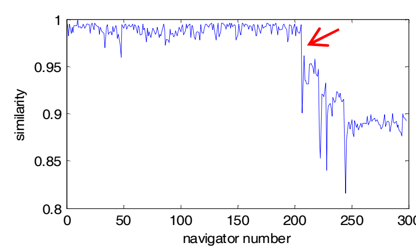

Fig.3 a significant change of similarity of acquired profiles shows the time when the motion happened in the knee examination.

References:

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