Real-Time Spiral MRI Using Nearest Neighbor Gridding

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Introduction: Real-time imaging incorporating fast data acquisition and near instantaneous image reconstruction is essential for interventional and other interactive MRI procedures. Several fast acquisition techniques can be used for real-time MRI, including fast GRE methods, BURST, RARE, GRASE, single-shot and interleaved EPI, and single-shot and interleaved spiral acquisition. These methods vary in terms of the SNR, spatial resolution, sensitivity to artifact, and temporal resolution achievable. Spiral acquisition methods have proven to be an effective and robust method for fast data acquisition, especially at the upper limits of temporal resolution.

Real-time MRI also requires fast image reconstruction. Several approaches for implementing real-time MR image reconstruction have been reported [1-4], including use of specialized hardware for 2D Fourier transform reconstruction [1,2], specialized hardware for projection reconstruction (PR) [3], and generalized implementation on a fast workstation [4]. For a limited class of spiral trajectories, real-time image reconstruction can be accomplished using PR as demonstrated in [3]; however, general reconstruction of spiral data is usually performed using gridding [5] followed by 2D Fourier transformation. Real-time implementation has been shown with the workstation system described in [4] at 16 frames/s for 128 x 128 matrices. Here we report on use of the dedicated hardware system described in [2] to perform spiral reconstructions at 30 frames/s for 256 x 256 matrices using a nearest neighbor gridding approach.

Methods: A spiral sequence, developed at Stanford University, was run on a GE Sigma 1.5 T MRI instrument equipped with Echo-Speed gradients (22 mT/m, 120 mT/m/ms). Real-time image reconstruction was performed using a PC-based reconstruction system [2] developed at the University of Arizona. The reconstruction system interfaces to the MRI instrument through the outputs of the fast receiver. The analog I and Q channels of the fast receiver connect to the two A/D inputs of the reconstruction system. The sample clock for the reconstruction system is derived from the SEQ output of the fast receiver. The scope trigger on the MRI instrument serves as a frame reset signal. Image reconstruction runs asynchronously to the data acquisition. An interface memory in the reconstruction hardware serves to accept data at whatever rate data are acquired and to deliver data to the reconstruction process in a continuous fashion, which results in a fixed 30 frame/s reconstruction of 256 x 256 pixel images from 256 x 256 complex data. Data are written to the interface memory in the order acquired and can be read out to the reconstruction process in any order desired. The read-out order is controlled by the sequence of addresses sent to the interface memory during the data read cycles. The sequence of addresses is determined by programmable values stored in an address memory.

The reconstruction system implements a discrete 2D Fourier transform. As currently configured, there is no capability for data interpolation, and therefore, a nearest neighbor gridding approach was utilized. In nearest neighbor gridding, the data for each Cartesian k-space point is set equal to the data of the nearest spiral k-space point. Given the known k-space points along the spiral trajectory, it is straightforward to determine the nearest neighbor mapping and to implement nearest neighbor gridding by loading the proper sequence of address values into the address memory. The approach was tested in phantoms and in cardiac imaging of adult volunteers. All cardiac imaging was done with a 5-inch surface coil and a gradient-echo spiral sequence with an acquisition bandwith of ±100 kHz. Two types of sequences were tested. One used a data acquisition window of 17 ms with 3520 data points per interleave, and the other a 40 ms acquisition window with 8000 data points per interleave. Various combinations of the number of interleaves and TR were tested.

Results and Discussion: The principal tradeoff for real-time imaging is between image quality and temporal resolution. As the acquisition frame rate increases, image quality, as measured by SNR and/or spatial resolution, decreases. Thus, errors associated with approximations such as nearest neighbor gridding become less significant at the high frame rates associated with real-time MRI. Figure 1 shows two images of the same data reconstructed with a “conventional” gridding algorithm, employing a Bessel function convolution kernel of half width two pixels (a), and the nearest neighbor gridding algorithm (b). There is little difference between these images in terms of image quality. These data were acquired with a two interleaf, 17 ms acquisition window, spiral sequence. TR was 50 ms yielding a frame rate (with 2 interleaves) of 10 frame/s. Because of the “sliding window” reconstruction at 30 frames/s, the effective frame rate with two interleaves is closer to 20 frame/s, which was fast enough to freeze even rapidly varying cardiac motion. Excellent real-time cardiac images were obtained, which is demonstrated by the result in Fig. 1b, but is more fully appreciated viewing the real-time imaging results.

Conclusion: Nearest neighbor gridding is adequate for real-time spiral imaging, especially at high frame rates where the SNR decrease and the added amount of artifact are small.

References: